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# Levels of Polycyclic Aromatic Hydrocarbons (PAHs) in Healthcare Waste Incinerators' Bottom Ash from Five County Hospitals in Kenya

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## Abstract

Health-care waste contains potentially harmful microorganisms and compounds which can infect and affect hospital patients, healthcare workers, the general public and environment. Therefore, management of health care waste requires safe handling, treatment and disposal procedures. While incineration reduces the volume and quantity of waste for final disposal, it leads to the production of fly and bottom ashes laden with toxic incomplete combustion products such as Polycyclic Aromatic Hydrocarbons (PAHs), dioxins, furans and heavy metals. This exposes workers who handle and dispose the bottom ashes, hospital patients, the general public and environment. The goal of this study was to determine the total and individual levels of 16 most prevalent and toxic PAHs. Bottom ash samples were collected from incinerators in five county hospitals in Kenya, namely; Moi-Voi, Narok, Kitale, Makindu and Isiolo. Bottom ash samples were collected over a period of six months from the five hospitals. The samples were then sieved, homogenised and stored at 4˚C in amber coloured glass containers. The PAHs were extracted using 30 ml of a hexane-acetone solvent (1:1) mixture by ultrasonication at room temperature (23˚C) for 45 minutes. The PAHs were then analyzed with a GC-MS spectrophotometer model (Shimadzu GCMS-QP2010 SE) connected to a computer work station was used for the PAHs analysis. The GC-MS was equipped with an SGE BPX5 GC capillary column (30 m × 0.25 mm × 0.25 μm) for the separation of compounds. Helium was used as the carrier gas at a flow rate of 15.5 ml/minute and 14.5 psi. 1 μl of the sample was injected at

280˚C, split mode (10:1). The oven programming was set for a total runtime of 40 minutes, which included: 100˚C (2-minute hold); 10˚C /min rise to 200˚C; 7˚C /min rise to 249˚C; 3˚C /min rise to 300˚C (2-minute hold). The interface temperature was set at 290˚C. Analysis was done in Selected Ion Monitoring (SIM) mode and the peak areas of each of the PAHs were collected from the chromatograph and used for quantification of the 16 PAHs listed by the U.S. Environmental Protection Agency (EPA) which included, BaA (benz[a]anthracene: 4 rings), BaP (benzo[a]pyrene: 5 rings), BbF (benzo [b]fluoranthene: 5 rings), BkF (benzo[k]fluoranthene: 5 rings), Chr (chrysene: 4 rings), DbA (dibenz[a,h]anthracene: 5 rings), InP (indeno[1,2,3 - cd] pyrene: 6 rings) and Acp (acenaphthene: 3 rings), Acpy (acenaphthylene: 3 rings), Ant (anthracene: 3 rings), BghiP (benzo[g,h,i]perylene: 6 rings), Flu (fluorene: 3 rings), FluA (fluoranthene: 4 rings), Nap (naphthalene: 2 rings), PhA (phenanthrene: 3 rings) and Pyr (pyrene: 4 rings). Ion source-interface temperature was set at 200˚C - 250˚C. Internal standards from Sigma Aldrich were used in the analysis and the acquired mass spectra data were then matched against the NIST 2014 library [1] [2]. The mean PAHs concentration in the bottom ashes of each hospital varied broadly from 0.001 mg/kg to 0.4845 mg/kg, and the mean total concentration levels of individual PAHs ranged from 0.0072 mg/kg to 1.171 mg/kg. Low molecular weight PAHs (Phenanthrene, Naphthalene and Fluorene) were predominant in all the hospital wastes whereas Kitale and Narok presented the lowest PAHs concentrations and the lowest number of individual PAHs. Moi/Voi recorded the highest total PAHs concentration at 1.3129 ± 0.0023 mg/kg from a total of 11 PAHs being detected from the bottom ash samples. Narok had only three PAHs being detected at very low concentrations of 0.0041 ± 0.00 mg/kg, 0.0076 ± 0.00 mg/kg and 0.012 ± 0.00 mg/kg for phenanthrene, anthracene and chrysene respectively. This study presents hospital incinerator bottom ash as containing detectable levels of both carcinogenic and non-carcinogenic PAHs. Continued unprotected exposure of hospital workers (waste handlers) to the bottom ash PAHs could be hazardous to their health because of their cumulative effect. Preventive measures e.g. the use of Personal protective equipment (PPE) should be prioritised to minimise direct contact with the bottom ash. The study recommends an upgrade on incinerator technology for efficient combustion processes thus for better pollution control.

## Keywords

PAHs, GC-MS, Healthcare Wastes, Disposal, Incinerator Bottom Ash

## 1. Introduction

Globally, management of healthcare waste has become a humanitarian issue because of its hazardous nature and the risks involved. Health care waste has therefore necessitated the need for it to be handled, transported, treated and disposed in a manner least harmful to the health of caregivers, patients and indi-

vidual members of the community and the environment [1] [2]. In the developing world, healthcare waste management is a human health and environmental burden that should be solved for improving sustainability. Poor healthcare waste management practices not only affect the health of those who come in contact with it, but also contributes to environmental degradation [3] [4]. Health care waste includes all the waste generated by hospitals, private surgeries, other health care facilities, diagnostic centers, research facilities and laboratories and dental practices [2] [5]. Healthcare waste management is an imperative environmental and public safety issue, due to its potential infectious and/or toxic character. Healthcare waste can be divided into two major categories: general waste which represents 80% of total healthcare waste; and hazardous health care waste (HHCW) which represent 20% of total healthcare waste. Explicitly, HHCW includes Infectious Healthcare Waste (IHCW), and other HHCW which includes different categories: chemicals, pharmaceuticals, genotoxic waste, and radioactive waste. Infectious Healthcare Waste (IHCW) is the waste type suspected to contain pathogens (bacteria, viruses, parasites or fungi), in sufficient concentration or quantity to cause disease in susceptible hosts [6]. Thus, IHCW management is a particularly high priority environmental concern, because inappropriate management of this type of waste may cause damage to human through injury by sharp instruments, infectious diseases such as HIV infection and hepatitis transmitted to humans due to proliferation of micro-organisms, environmental pollution and as well as contamination of ground water [7]. Healthcare waste plays an important role in the transmission and intensification of disease, an issue that is of a growing concern in developing countries [8] [9]. Hazards associated with waste produced by healthcare facilities, and the increased potential for infection and injury. Many countries maintain stringent management systems for handling and safe disposal of healthcare waste to minimize the risk [10]. The growing global population, the increase in lifespan, and the global crisis in chronic disease mean not only is more HCW being produced than ever before but there is an even greater need to better manage it [11].

As population continue to increase means a surge in use of HCW disposal practices such as landfilling, composting and incineration [12]. When proper disposal techniques are carried out incorrectly, such as incineration, there is risk of emission of pollutants like acid gases, oxides of nitrogen, metals, particulate matter and sulphur [13]. Thus, it is essential to ensure that incinerators are operated as per advanced technological and legislation to have clean and safe processes [14]. There is need to use the right waste treatment equipment, develop training curriculum for those involved operation and maintenance, develop standard operating procedures to avoid disastrous effects on the environment and in turn, on human health [15].

Efforts have been made to push for "greener" and "safer" means of HCW disposal such as autoclaving, microwaving and steam augor. However, even green methods come with potential challenges as some are not suitable for large volumes of waste or are not widely available [16]. Moreover, these methods tend to

be supportive to conventional techniques than being their replacement. Such as a steam autoclave can sterilize bacteria in clinical solid waste but cannot be considered as an alternative technology to incineration due to the re-growth risk of the bacteria [17].

The global health consequences of HCW disposal methods often differ depending on how developed the country is [18]. WHO [19] estimates that 85% of HCW is non-hazardous, despite this, the methods taken to dispose of the waste such as incineration and landfilling can lead to the production of hazardous chemicals and pollutants that can damage the environment and have global health consequences. Pollution is the greatest environmental cause of disease and premature death around the globe and the healthcare sector has been noted for being a significant contributor to acid rain, greenhouse gas emissions, smog, air pollutants, stratospheric ozone depletion and carcinogenic and non-carcinogenic air toxics [20]. Inefficiencies in landfilling process has been noted for producing airborne contaminants such as dioxins and furans that increase the likelihood of cancer, liver failure and various respiratory diseases [21]. There has been a clear link between the increased risk of non-communicable disease and increased exposure to pollution ([22] [23]). There has also been a growing agreement amongst public health experts that air pollution, even at tolerable levels, aggravates morbidity particularly in respiratory and cardiovascular diseases and leads to premature mortality [24]. Pollutants such as Carbon monoxide, Carbon Dioxide, Nitrogen oxides and Sulfur Dioxide from HCW disposal have led to global warming and as such many related diseases have affected global populations ([25] [26]). Global warming has also led to the emergence of numerous parasitic diseases, often in parts of the world never previously seen [27].

In developed countries, technologies such as autoclaving and incineration are used for treatment of healthcare waste. However, in developing countries, health care waste has not received adequate attention particularly when it is disposed of together with domestic waste. As a consequence, healthcare waste causes diseases amongst waste handlers, incinerator operators and recycling waste operators [28] [29]. Furthermore, it has been reported that healthcare waste presents an increasingly high risk to medical doctors, nurses, healthcare auxiliaries and hospital maintenance personnel, patients in healthcare facilities or receiving home care, visitors to healthcare facilities, workers in support services, such as cleaners, people who work in laundries, workers transporting waste to a treatment or disposal facility and workers in waste-management facilities (such as landfills or treatment plants), as well as informal recyclers (scavengers) [30] [31].

Several healthcare waste management systems have been employed including incineration, steam sterilization, microwave sanitation, chemical disinfection, dry heat disinfection and superheated steam disinfection but the best available technology for treatment of healthcare waste is incineration [30] [32]. The incineration process destroys pathogens and reduces the waste volume by 90% and weight by 75%. Incineration usually involves the combustion of mingled solid waste in the presence of air or sufficient oxygen. Typically, the temperature in

the incinerator is more than 850˚C and the waste is converted into carbon dioxide and water [11] [33].

The incineration of healthcare wastes not only releases toxic acid gases (CO, $CO_2$, $NO_2$, $SO_2$), dioxides into the environment but also leaves a solid material called ash as residue and includes bottom ash and fly ash which increases the levels of heavy metals, inorganic salts and organic compounds in the environment [34]. Most of the ash produced is bottom ash that is the residues inside the burner after incineration. Fly ash settles on post burner equipment such as scrubbers. The ash when melted at 1200˚C is converted into slag by cooling at room temperature. Metals are not destroyed during incineration, and are often released into the environment along with ash. Disposal of ash in landfill without proper treatment may cause contamination of groundwater due to leachate [35]. Incinerators increase particulate pollution and reduce life expectancy. The magnitude of the association between fine particles and mortality suggests that controlling fine particles would result in saving thousands of early deaths each year" and "there is consistent evidence that fine particulates are associated with increased cardiac and respiratory mortality [36] [37].

Polycyclic aromatic hydrocarbons (PAHs) are a broad group of benzene-loaded organic compounds that make up part of persistent organic pollutants (POPs), usually produced when there is incomplete burning of matter. With the rapid urbanization and increasing scarcity of land resources, traditional landfill disposal methods are no longer suitable for the needs of urban development [38]. Incineration, which converts waste into energy to achieve resource utilization, is considered as one of the main methods for managing MSW [39]. Studies have shown that the incineration of MSW constitutes an emission source of some toxic pollutants, including PAHs [40], polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs) [41]. In addition to the above pollutants, various by-products in the residues formed during the incineration process can migrate to the environment [37], leading to potential environmental impacts and health risks [42]. PAHs are a subject of colossal concern due to their infamous properties as being DNA mutagens, carcinogenic and embryotoxic [43]. By the agency of anthropogenicity and rapid industrialization, a wide variety of PAHs have been produced over the years, with their physicochemical properties aiding in their mobility and persistence in the different environmental compartments. This includes their molecular weight, which governs the melting/boiling point and lipophilicity. The number of benzene-rings included in the structure, less than 3 rings allow perfect mobility in the atmosphere as 5 to 7-ringed members percolate in water systems and/or (ad)absorbed into other solid systems, to finally end up into the food chain and taken up by people or animals. This also narrows down exposure pathways to inhalation, dermal or ingestion [44].

Long-term exposure leads to idiopathic infertility as the PAHs get metabolised and bind to the DNA to alter transcription processes [45]; inflammation and oxidative stress caused by the overexpression of pro-inflammatory proteins in body tissues [46]; embryotic growth malformations emanating from cardiac

toxicity caused by the ringed PAHs binding to the aryl hydrocarbon receptor (AhR) [47]; cardiovascular diseases like stroke and atherosclerosis due to cardio-metabolism [48]. Other short term exposure health issues include irritation, nausea, diarrhoea, vomiting, inflammation [49] [50]. The United States Environmental Protection Agency (US EPA) in 1970 proposed 16 PAHs out of the hundreds and assigned them to be high priority pollutants to humans emanating from their exposure. These included seven carcinogenic; BaA (benz[a]anthracene: 4 rings), BaP (benzo[a]pyrene: 5 rings), BbF (benzo[b]fluoranthene: 5 rings), BkF (benzo[k]fluoranthene: 5 rings), Chr (chrysene: 4 rings), DbA (dibenz[a,h]anthracene: 5 rings), InP (indeno[1,2,3 - cd] pyrene: 6 rings) and 9 non-carcinogenic; Acp (acenaphthene: 3 rings), Acpy (acenaphthylene: 3 rings), Ant (anthracene: 3 rings), BghiP (benzo[g,h,i]perylene: 6 rings), Flu (fluorene: 3 rings), FluA (fluoranthene: 4 rings), Nap (naphthalene: 2 rings), PhA (phenanthrene: 3 rings) and Pyr (pyrene: 4 rings) [51] [52].

Disposing incinerator bottom ash after incineration has become a great challenge because of population growth, lack of land for landfills and the strict regulations and laws. Recycling is the run-to option where ash, now looked at as a valuable resource, is recycled and reused in construction material, thus supporting sustainable development [53]. This implies therefore that the physicochemical properties of this bottom ash have to be thoroughly investigated before it is used elsewhere. The main objective of this work was to quantify the total and individual content of the 16 US EPA PAHs sampled from incinerator bottom ash across five hospitals: Moi-Voi, Narok, Kitale, Makindu and Isiolo, all in Kenya.

## 2. Materials and Methods

### 2.1. Chemical and Reagents

The 16 US EPA priority PAHs standards were purchased from Sigma Aldrich. High Performance Liquid Chromatography (HPLC) grade dichloromethane and hexane were purchased from Kobian Chemicals Nairobi, Kenya. Other disposables included Nylon syringe filters (0.45 µm, 17 mm diameter), adjustable-volume micropipettes (20 - 1000 µl), SPE Cartridges and clear tube and amber glass injection vials (2 mL) were also obtained from Kobian.

### 2.2. Study Areas

The bottom ash samples were collected at five different county hospitals from their waste incinerator sites (as shown in **Figure 1**). This included Kitale County hospital (1.0167˚N, 35.0000˚E) (KTL), Isiolo County hospital (0.3500˚N, 37.5833˚E) (ISO), Narok County hospital (1.0833˚ S, 35.8667˚E) (NRK), Makindu County hospital (2˚16'30.00"S, 37˚49'12.00"E) (MKD), Moi-Voi County hospital (3.3833˚S, 38.5667˚E) (MVI). Samples were stored in airtight amber coloured glass jars and wrapped in foil then transported to the laboratory for processing. The ashes were then dried in the oven at 50˚C, homogenised by grinding with pestle and mortar then sieved before storage at 4˚C before extraction.

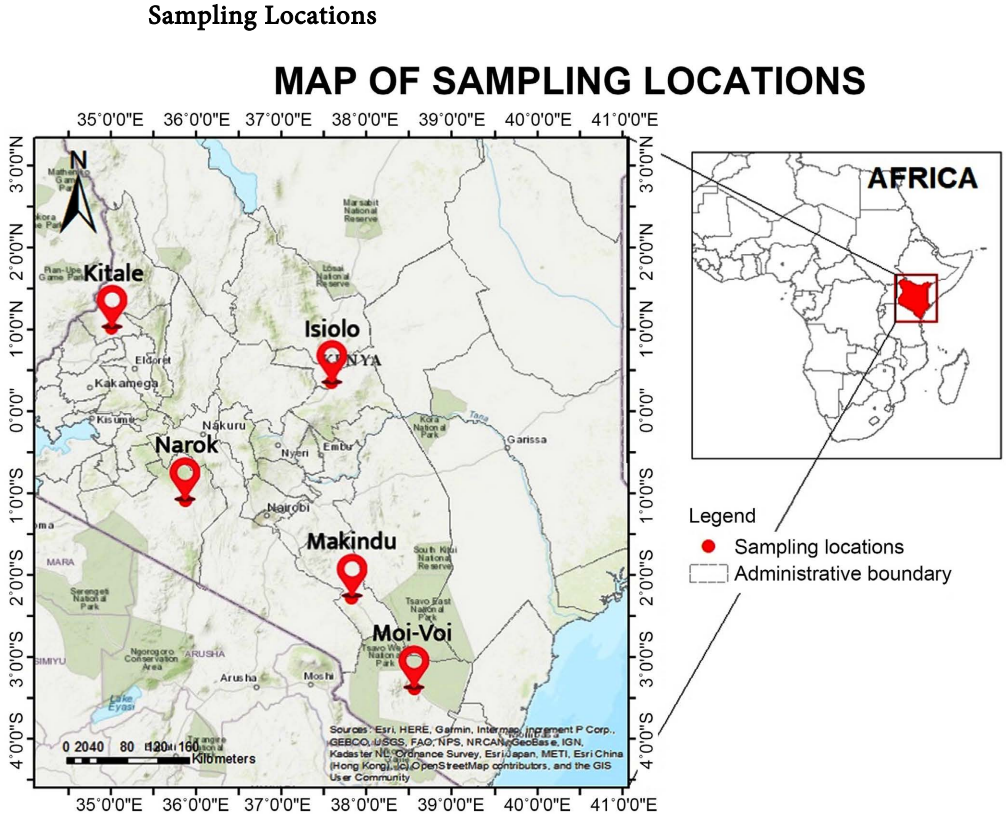


**Figure 1.** County hospitals sampling locations for the incinerator bottom ashes.

## 2.3. Incinerator Bottom Ash Sampling

Portions of bottom ash were collected each month from each of the five selected county hospitals for six months to ensure randomness of the samples and homogenized for each hospital to form a composite sample from which laboratory samples were drawn. Samples were stored in 500 g amber coloured glass bottles. These were then clearly labelled, stored and transported to the laboratory for analysis.

## 2.4. Sample Treatment and Extraction

Portions from the composite samples were sieved and ground using different sizes of mesh and separated from poorly burnt materials such as syringes, needles, glasses and scalpels. Laboratory samples of (10 g were extracted using 30 ml of a hexane-acetone solvent (1:1) mixture by ultrasonication at room temperature (23˚C) for 45 minutes. This was then filtered using Whatman® No. 42 filter paper, where 4 ml of the extract was pipetted out and reconcentrated in a miVac DNA Concentrator (Genevac) to 1 ml. C18 (500 mg). The sample was prepared and the solid phase extraction (SPE) cartridge (C18) was conditioned with 3 ml methanol and then equilibrated with 3 ml HPLC grade water. The sample was then loaded into the SPE cartridge and impurities washed with 5% methanol, 95% water. The cartridge was left to dry in a stream of air for 10 minutes after which, elution was done with 3ml methanol and then concentrated to

1 ml. This was then filtered using Nylon Syringe Filters (0.45 um) into 2 ml vials in preparation for GC-MS analysis as described by [54].

### 2.5. Preparation of PAHs Standard Solutions

Individual stock solutions of concentration 1000 ppm for each of the PAHs were prepared by diluting from the original 2 g/ml. Working standards at 20 mg/ml concentration were then prepared from this stock. From the working standards, a range of standard solutions from 10 - 400 ng/ml were prepared for the different PAHs and stored in amber glass vials at 4˚C to be used as calibration standards.

### 2.6. GC-MS Analysis

A Gas Chromatograph-Mass spectrophotometer (GC-MS) model; Shimadzu GCSMS-QP2010 SE, connected to a computer work station was used for the PAHs analysis. The GC-MS was equipped with an SGE BPX5 GC capillary column (30 m × 0.25 mm × 0.25 µm) for the separation of compounds. Helium was used as the carrier gas at a flow rate of 15.5 ml/minute and 14.5 psi. 1 µl of the sample was injected at 280˚C, split mode (10:1). The oven programming was set for a total runtime of 40 minutes, which included: 100˚C (2-minute hold); 10˚C /min rise to 200˚C; 7˚C /min rise to 249˚C; 3˚C /min rise to 300˚C (2-minute hold). The interface temperature was set at 290˚C. Analysis was done in Selected Ion Monitoring (SIM) mode and the peak areas of each of the PAHs were collected from the chromatograph and used for quantification of the 16 PAHs listed by the U.S. Environmental Protection Agency (EPA). Ion source-interface temperature was set at 200˚C - 250˚C. The acquired mass spectra data were then matched against the NIST 2014 library [1] [2].

## 3. Results and Discussion

### 3.1. GC-MS Analysis

Each of the 16 EPA PAHs: as identified from the sample using their retention times from the chromatographs and their respective m/z values *i.e.*, 128, 152, 154, 166, 178, 202, 228, 252, 278 and 276 from the mass spectra data. Quantification was done using a linear regression model based on a 6-point calibration curve (10 - 400 ng/ml) from earlier prepared PAHs standard solutions. The calibration curves showed acceptable linearity having correlation (R) values above 0.9982 for each of the PAHs (as shown in **Table 1**, **Table 2** and **Figure 2**).

### 3.2. Levels of PAHs in Each of the Selected Regions

The levels of all the 16 PAHs in each county hospital were summarized in **Table 3** and **Table 4**.

As represented in **Figure 3**, Naphthalene was detected in all regions including Moi/Voi (open) (0.1692) which was the highest concentrations. Isiolo registered a 0.001 value while Kitale had zero concentration of Naphthalene. Moi/Voi also

**Table 1.** MS-SIM data acquisition parameters.

| No. | Start Time (min) | End Time (min) | m/z | PAHs |
|---|---|---|---|---|
| 1 | 5.00 | 5.90 | 128 | Naphthalene |
| 2 | 9.00 | 9.75 | 152 | Acenaphthylene |
| 3 | 9.76 | 10.50 | 154 | Acenaphthene |
| 4 | 10.60 | 11.50 | 166 | Fluorene |
| 5 | 13.40 | 14.50 | 178 | Phenanthrene |
| 6 | 13.90 | 14.13 | 178 | Anthracene |
| 7 | 17.00 | 17.80 | 202 | Fluoranthene |
| 8 | 17.90 | 18.50 | 202 | Pyrene |
| 9 | 22.00 | 23.10 | 228 | Benz[a]anthracene |
| 10 | 23.016 | 24.65 | 228 | Chrysene |
| 11 | 28.00 | 29.50 | 252 | Benzo[b]fluoranthene |
| 12 | 28.871 | 29.97 | 252 | Benzo[k]fluoranthene |
| 13 | 30.00 | 31.00 | 252 | Benzo[a]pyrene |
| 14 | 36.00 | 37.60 | 276 | Indeno[1,2,3 - cd]pyrene |
| 15 | 37.00 | 38.08 | 278 | Dibenz[a,h]anthracene |
| 16 | 38.17 | 39.00 | 276 | Benzo[ghi]perylene |

**Table 2.** Chromatogram peak labelling for the corresponding PAHs standards and their retention time (min).

| Peak No. | Retention time (min) | m/z | PAHs |
|---|---|---|---|
| 1 | 5.564 | 128 | Naphthalene |
| 2 | 9.906 | 152 | Acenaphthylene |
| 3 | 9.830 | 154 | Acenaphthene |
| 4 | 11.171 | 166 | Fluorene |
| 5 | 13.743 | 178 | Phenanthrene |
| 6 | 13.892 | 178 | Anthracene |
| 7 | 17.341 | 202 | Fluoranthene |
| 8 | 18.078 | 202 | Pyrene |
| 9 | 22.291 | 228 | Benzo(a)anthracene |
| 10 | 23.016 | 228 | Chrysene |
| 11 | 28.729 | 252 | Benzo(b)Fluoranthene |
| 12 | 28.945 | 252 | Benzo(k)Fluoranthene |
| 13 | 30.178 | 252 | Benzo(a)pyrene |
| 14 | 36.753 | 276 | Indeno(1,2,3 - cd)pyrene |
| 15 | 37.453 | 278 | Dibenzo(a,h)anthracene |
| 16 | 38.168 | 276 | Benzo(g,h,i)perylene |

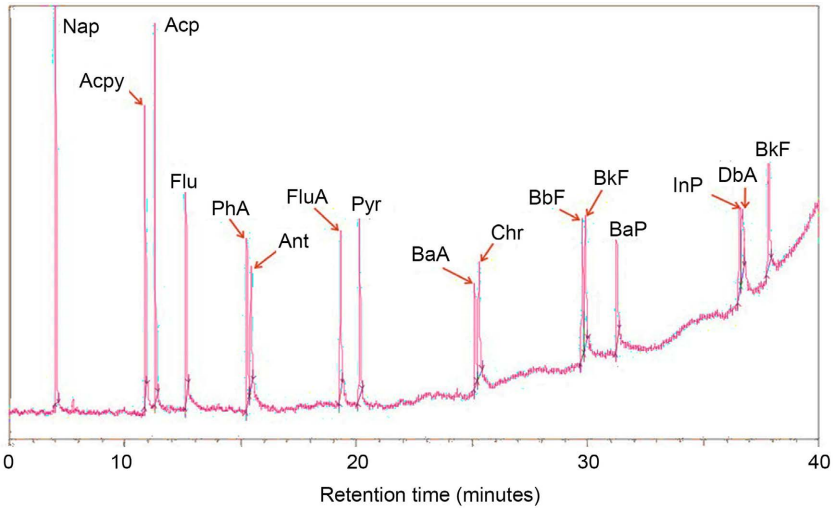


**Figure 2.** GC-MS Total Ion Chromatogram (TIC) for the 16 EPA PAHs calibration standards.

**Table 3.** Regional concentration values of each of the analysed PAHs.

| PAHs | LOD (mg/kg) | LOQ (mg/kg) |
|---|---|---|
| Naphthalene | 5.5418 | 16.7933 |
| Acenaphthylene | 8.0512 | 24.3974 |
| Acenaphthene | 12.6422 | 38.3098 |
| Fluorene | 13.8522 | 41.9763 |
| Phenanthrene | 17.0655 | 51.7139 |
| Anthracene | 18.3859 | 55.7148 |
| Fluoranthene | 10.6908 | 32.3965 |
| Pyrene | 5.30817 | 16.0853 |
| Benzo(a)anthracene | 26.0723 | 79.0070 |
| Chrysene | 64.7658 | 196.260 |
| Benzo(b)Fluoranthene | 17.7069 | 53.6573 |
| Benzo(k)Fluoranthene | 94.2832 | 285.706 |
| Benzo(a)pyrene | 33.5375 | 101.629 |
| Indeno(1,2,3 - cd)pyrene | 6.37729 | 19.3251 |
| Dibenzo(a,h)anthracene | 0 | 0 |
| Benzo(g,h,i)perylene | 60.9342 | 184.649 |

had the highest concentration of acenaphthylene at 0.0279, followed by Makindu at 0.0125. Moi/Voi (open) showed concentration levels of 0.0063. Acenaphthylene was not detected in both Isiolo and Kitale. Isiolo and Kitale also showed zero concentration values for acenaphthene. Moi/Voi showed the highest (0.0173) as Moi/Voi (open) averaged at 0.0094. Moi/Voi had highest concentration of fluorene (0.2123) as other regions registered lower value at 0.0338, 0.0318, 0.042 for Makindu., Moi/Voi (open) and Isiolo respectively.

**Table 4.** Concentration of each of the analyzed PAHs with corresponding regions (sample location).

| PAHs | Concentration (ug/kg) | | | | | |
|---|---|---|---|---|---|---|
| | Kitale | Makindu | Moi-Voi | Moi-Voi (open) | Isiolo | Narok |
| Naphthalene | 169.8 ± 0.7.99 | 1.00 ± 0.0512 | 133.9 ± 0.000464 | 169.2 ± 0.00692 | 66.8 ± 0.00233 | <LOD |
| Acenaphthylene | 6.3 ± 0.233 | <LOD | 27.9 ± 0.00943 | 6.3 ± 0.0821 | 12.5 ± 0.0235 | <LOD |
| Acenaphthene (ug/kg) | 9.4 ± 0.00 | <LOD | 17.3 ± 0.00 | 9.4 ± 0.00 | 4.6 ± 0.00 | <LOD |
| Fluorene (ug/kg) | 31.8 ± 0.00 | 4.2 ± 0.00 | 212.3 ± 0.00 | 31.8 ± 0.00 | 33.8 ± 0.00 | <LOD |
| Phenanthrene | 266.2 ± 0.0672 | 37.9 ± 0.0796 | 484.5 ± 0.0853 | 265.6 ± 0.168 | 112.7 ± 0.196 | 4.1 ± 0.00 |
| Anthracene | <LOD | <LOD | 0.0589 ± 8.41E-4 | <LOD | 0.0251 ± 4.78E-4 | 0.0076 ± 0.00 |
| Fluoranthene | 42.00 ± 0.0178 | 11.4 ± 0.0307 | 104.7 ± 0.159 | 42.00 ± 0.0278 | 41.00 ± 0.0178 | <LOD |
| Pyrene | 36.9 ± 0.0371 | 8.7 ± 0.0113 | 115.1 ± 0.287 | 37.00 ± 0.099 | 47.3 ± 0.516 | <LOD |
| Benzo(a)anthracene | 13.2 ± 0.0748 | 42.7 ± 0.00693 | 38.00 ± 0.0184 | 13.1 ± 0.0521 | 45.2 ± 0.0488 | <LOD |
| Chrysene | 52.7 ± 0.043 | 31.2 ± 0.0337 | 103.9 ± 0.0223 | 52.7 ± 0.0115 | 24.2 ± 0.923 | 12.00 ± 0.00 |
| Benzo(b)Fluoranthene | 16.1 ± 0.417 | 10.9 ± 0.0154 | 16.4 ± 0.0908 | 17.1 ± 0.968 | 45.9 ± 0.103 | <LOD |
| Benzo(k)Fluoranthene | 24.7 ± 0.0721 | <LOD | <LOD | 24.9 ± 0.198 | <LOD | <LOD |
| Benzo(a)pyrene | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD |
| Indeno(1,2,3 - cd)pyrene | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD |
| Dibenzo(a,h)anthracene | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD |
| Benzo(g,h,i)perylene | <LOD | 7.2 ± 0.0261 | <LOD | <LOD | <LOD | <LOD |

It was not detected in Kitale. Kitale also had the lowest concentration of phenanthrene at 0.0041. Narok and Moi/Voi (open) averaged at 0.2662 whilst Moi/Voi recorded the highest at 0.4845. Anthracene was not detected in Isiolo, Moi/Voi (open). Makindu, Narok and Kitale recorded concentration values of 0.0251, 0.0076, 0.0076 respectively, which are below the allowable limit of 0.03 [55]. Moi/Voi showed a very high concentration (0.1074) of fluoranthene, as compared to the other locations, which was also above the allowable limits at 0.03. Makindu and Moi/Voi (open) depicted values very close to the allowable 0.04 limit on the higher side *i.e.* 0.0410 and 0.0420 respectively. In all regions, pyrene was present with Moi/Voi having the highest value at 0.1151. Except for Isiolo (0.0087), all other region registered values above 0.03 (allowable limit) at 0.0473, 0.0370 for Makindu and Moi/Voi (open) respectively. For benz[a]anthracene, Makindu recorded the highest value at 0.0452. Moi/Voi (open) had much lower values at 0.0131 while Kitale's and Narok's were undetected. Chrysene was also detected in all regions. Leading at 0.1039 is Moi/Voi whilst Kitale had the lowest (0.0120). Makindu also showed the highest concentration of benzo[b]fluoranthene at 0.0459, as other regions averaged closely at 0.0164, 0.0161, 0.0109 and 0.0171 for Moi/Voi, Narok, Isiolo and Moi/Voi open. Kitale showed no readings. Benzo

[k]fluoranthene was not detected in all regions except for Moi/Voi (open) at 0.0249. Except for Isiolo (0.0072), benzo[g,h,i]perylene was not detected anywhere else. All concentration values were recorded in mg/kg.

Figure 4 represents the overall total concentration levels of each of the PAHs in all the sampled locations.

Phenanthrene was the most abundant PAH totaling at 1.1619 mg/kg. Naphthalene came in second with a total concentration of 0.5407 mg/kg. Tightly

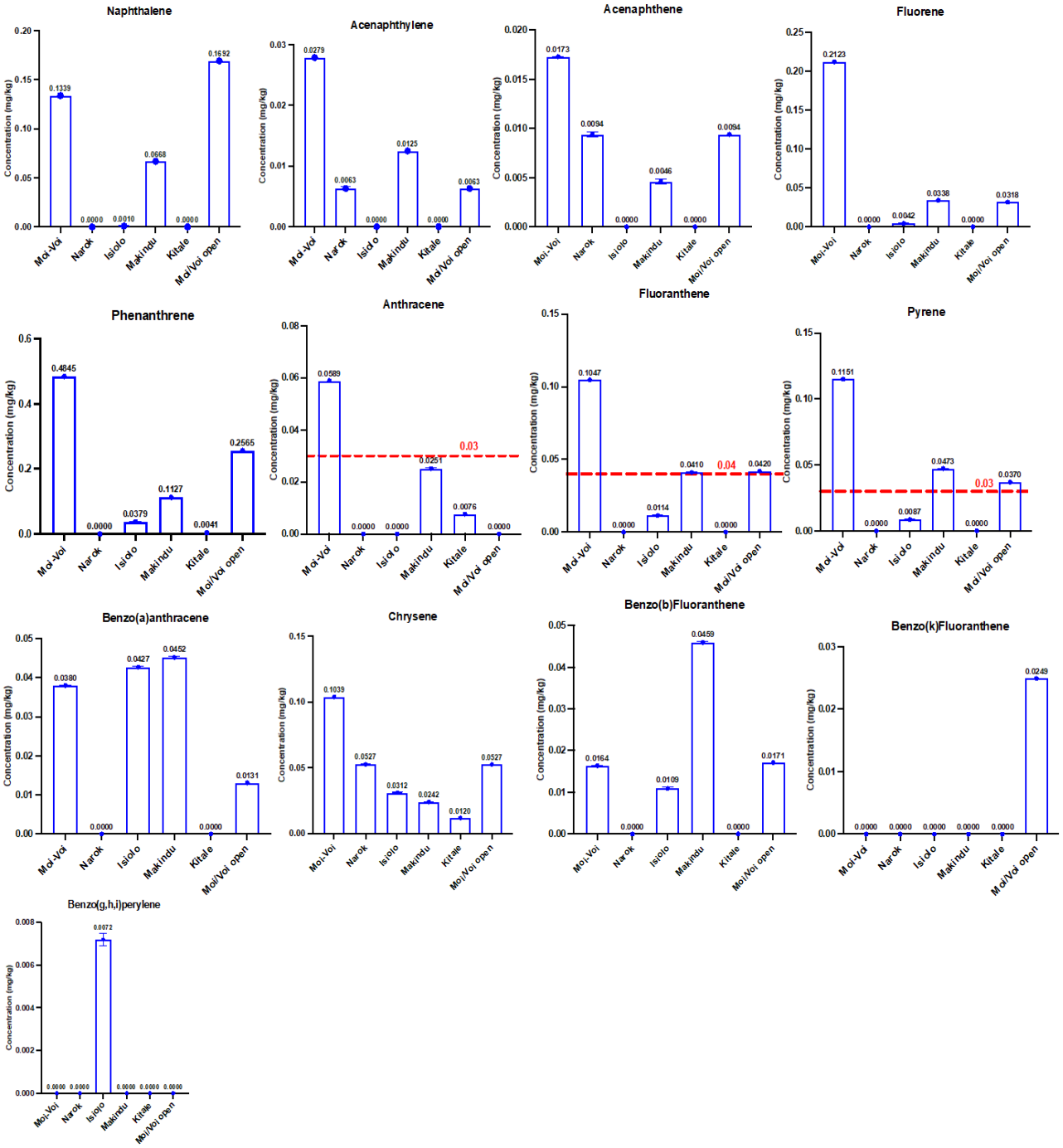


Figure 3. Individual PAHs concentration on sample locations and their recommended concentration levels.

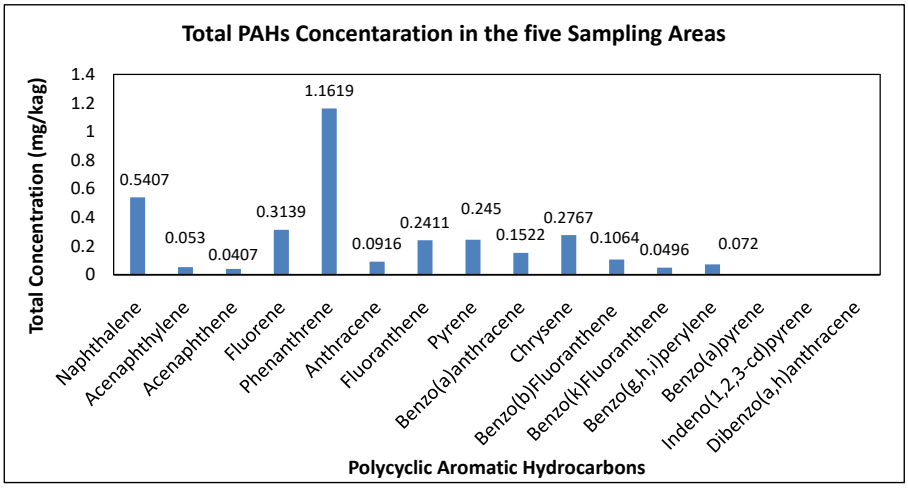


**Figure 4.** Total concentration of polycyclic aromatic hydrocarbons across the sampling locations.

ranging values of 0.3139, 0.2411, 0.245, 0.2767 from fluorene, fluoranthene, pyrene and chrysene respectively were also recorded which formed another concentration medium to low range. Acenaphthylene, acenaphthene, anthracene, benz[a]anthracene, benzo[b]fluoranthene and benzo[k]fluoranthene at 0.053, 0.0407, 0.0916, 0.1522, 0.1064 and 0.0496 were clustered in the very low concentration range as benzo[g,h,i]perylene was the very least of them all at 0.072. This is so since it was only detected in Makindu. Benzo[a]pyrene, indeno[1,2,3 - cd] pyrene and dibenz[a,h]anthracene were not detected in any of the regions.

The total concentration of PAHs from the sampling locations are presented in **Figure 5**. Moi/Voi had the highest value at 1.3129 mg/kg followed by Kitale, Isiolo and Moi/Voi (open) 0.6691 and 0.4591, 0.66 mg/kg. Makindu and Narok had very low total PAHs concentrations at 0.1552 and 0.0237 as only 2 PAHs *i.e.* phenanthrene and anthracene were detected in Narok. These mean values are much lower than the ones observed in other literatures about concentration levels of PAHs in hospital waste incinerator bottom ashes. This could be attributed to the differences in the methodologies used for sample preparation and analysis, incinerator combustion parameters and also the dynamic nature of the waste composition acquired from each hospital [56]. Nevertheless, more studies should be done to ascertain the magnitude of the effect these factors and many others not captured herein have. A summary of the number of PAHs for each region is presented in **Table 5**.

[57] reports PAHs in Municipal waste bottom ash, between 7 and 463 mg/kg have been set as acceptable concentration ranges for selected carcinogenic PAHs *i.e.* B[a]anth, Chrys, B[b]flu, B[k]flu, B[a]pyr, I[123cd] pyr and DB[ah]anth. The high mean levels of PAHs from Moi/Voi could be attributed to the operating conditions e.g., temperature, of this hospital's incinerator, which could favour the formation of PAHs. As shown in **Table 5** and **Table 6**, Low-molecular (LMW) and medium molecular weight (MMW) PAHs were predominant in the bottom ashes. Results of the present study agree with those reported by [56].

Results further indicate that there are no significant differences in PAHs concentration levels between the values from the Moi/Voi open burning site and the closed incinerator.

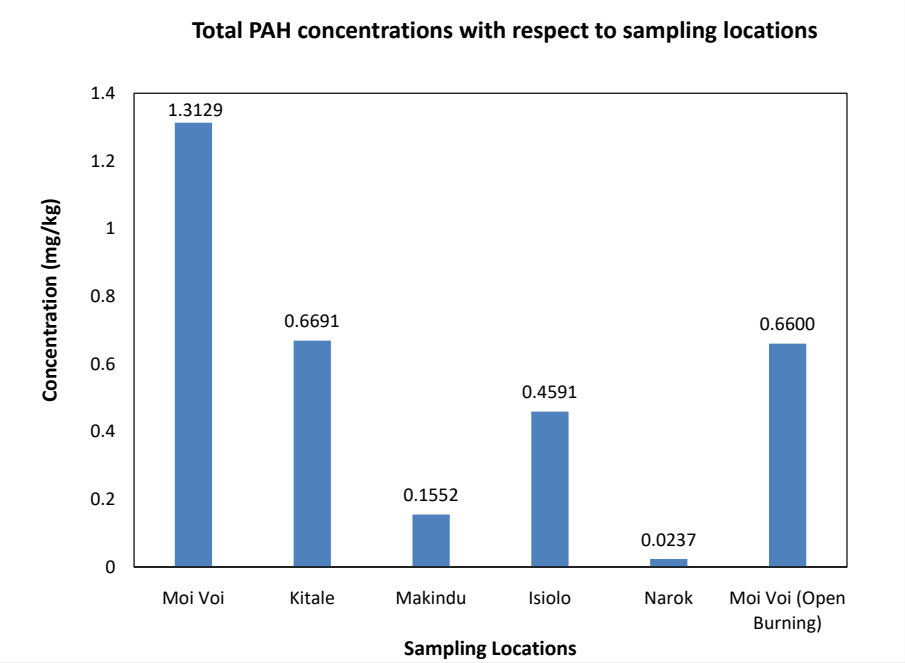


Figure 5. Total PAHs concentration with respect to sampling locations.

Table 5. Distribution of the PAHs in the sample locations.

| No. | PAHs | # of rings | Carcinogenicity level | Locations found |
|---|---|---|---|---|
| 1 | Naphthalene | 2 | I | Moi/Voi, Moi/Voi (open), Makindu |
| 2 | Acenaphthylene | 3 | I | Moi/Voi, Moi/Voi (open), Makindu |
| 3 | Acenaphthene | 4 | I | Moi/Voi, Moi/Voi (open), Makindu |
| 4 | Fluorene | 3 | I | Moi/Voi, Moi/Voi (open), Makindu, Isiolo |
| 5 | Phenanthrene | 3 | III | Moi/Voi, Moi/Voi (open), Narok, Makindu, Isiolo |
| 6 | Anthracene | 3 | I | Moi/Voi, Narok, Makindu, Kitale |
| 7 | Fluoranthene | 4 | I | Moi/Voi, Moi/Voi (open), Makindu, Isiolo |
| 8 | Pyrene | 4 | III | Moi/Voi, Moi/Voi (open), Makindu, Isiolo |
| 9 | Chrysene | 4 | III | All |
| 10 | Benzo(a)anthracene | 5 | II | Moi/Voi, Moi/Voi (open), Makindu, Isiolo |
| 11 | Benzo(b)Fluoranthene | 5 | II | Moi/Voi, Moi/Voi (open), Makindu, Isiolo |
| 12 | Benzo(k)Fluoranthene | 5 | II | Moi/Voi (open) |
| 13 | Benzo(a)pyrene | 5 | III | None |
| 14 | Indeno(1,2,3-cd)pyrene | 6 | III | None |
| 15 | Dibenzo(a,h)anthracene | 5 | II | None |
| 16 | Benzo(g,h,i)perylene | 6 | II | Isiolo |

**Table 6.** Total number of PAHs detected in each region.

| No. | Region | Total No. of PAHs | | |
|---|---|---|---|---|
| | | PAHs carcinogenic level | | |
| | | I | II | III |
| 1 | Moi/Voi | 6 | 2 | 3 |
| 2 | Kitale | 1 | 0 | 1 |
| 3 | Moi/Voi (open) | 5 | 3 | 3 |
| 4 | Isiolo | 1 | 3 | 3 |
| 5 | Narok | 2 | - | 1 |
| 6 | Makindu | 6 | 2 | 3 |

## 4. Conclusions and Recommendations

This study reports successful extraction and quantification of 16 US-EPA PAHs from five County hospitals' incinerator bottom ash using GC-MS. The huge differences in mean PAHs levels in each hospital demonstrate the effect the type of incinerator has on the overall production of PAHs. Moi/Voi recorded the highest total PAHs concentration at 1.3129 mg/kg from a total of 11 PAHs being detected from the bottom ash samples. Narok had only three PAHs being detected at very low levels of 0.0041 mg/kg, 0.0076 mg/kg and 0.012 mg/kg for phenanthrene, anthracene and chrysene respectively. Phenanthrene was the most common of all PAHs with a total mean concentration of 1.1619 mg/kg, while Benzo [a]pyrene, indeno[1,2,3 - cd] pyrene and dibenz[a,h]anthracene were not detected in any of the regions. Even though bottom ash is not fully classified as a hazardous material, this study shows that bottom ashes from hospital incinerator do contain some levels of PAHs and thereby need to be specially treated before handling or disposal.

The study recommends that all workers in the incinerators sampled should be provided with personal protective equipment to caution them from risks of exposure of the identified PAHs. The study also recommends that operation of the incinerators be improved and scrubbing devices installed in all health care waste treatment incinerators. The ash could be recyclable as construction material, but it must be treated at high temperature (850˚C - 1000˚C) so as to destroy the PAHs before or during the recycling process. Finally, there is need for the policy makers to target health care workers for training focusing on waste segregation and operation and maintenance for incinerator operators.

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## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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