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Antibiotic Residues in Incinerator Ash from Medical Facilities in Nakuru Town, Kenya: Implications for Environmental Safety

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Abstract

The purpose of this study was to analyse incinerator ashes from two medical facilities in Nakuru Town, Kenya, namely Lakey Hospital and Rifty Hospital, to determine the concentrations of Metronidazole, Benzyl penicillin, and Ceftriaxone before the ash was released into the environment. Pharmaceutical wastes constitute approximately 15 per cent of global medical waste and pose risks to environmental and public health. The study adopted a longitudinal research design, with ash samples collected weekly for three weeks from incinerators at both hospitals and fly ash from the chimney of Rifty Hospital. Composite samples were prepared by collecting ash from different points using a stainless-steel spade. Solid Phase Extraction was employed to pre-treat the samples, which were subsequently analysed by High-Performance Liquid Chromatography using a UV detector. Differences in antibiotic concentrations according to sampling location and antibiotic type were evaluated using two-way Analysis of Variance. Benzyl penicillin concentrations in Lakey and Rifty hospital ashes were 24,111.51 µg/ml and 1,281.08 µg/ml, respectively, while Ceftriaxone concentrations were 192,944.27 µg/ml and 5,049.70 µg/ml, respectively. Metronidazole was absent in Lakey Hospital ash but recorded at 265.33 µg/ml in Rifty Hospital ash. Rifty Hospital fly ash contained Benzyl penicillin (588.9 µg/ml) and Ceftriaxone (273.5 µg/ml). Detected concentrations substantially exceeded the respective CLSI breakpoints, indicating potential environmental contamination and antimicrobial resistance risks. The study recommends regular inspection of incinerators, disposal of final ash in sanitary landfills, and strengthened regulatory monitoring before environmental release.

Key terms: Antibiotic residues, high-performance liquid chromatography, incinerator ash, minimal inhibitory concentration, pharmaceutical waste disposal.

1.0 INTRODUCTION

Pharmaceutical wastes comprise 15 per cent of the global medical wastes that threaten the environment and public health (Oweis et al., 2005). In Africa, pharmaceutical waste handling in medical facilities is a serious concern, with only a few governments providing practical guidelines for their management (World Health Organization, 2022). In Kenya, the National Health Care Wastes Management action plan was developed to provide feasible options and a five-year roadmap for managing healthcare waste, with the primary goal of providing health managers with direction in the planning, implementation, and monitoring of waste management operations in health institutions (Ministry of Health, 2015). Despite the existence of this framework, compliance with legal requirements for pharmaceutical waste management remains inadequate in many health facilities, largely due to insufficient training of healthcare personnel and weak enforcement by regulatory authorities (Jovanovic et al., 2016).

Antibiotics are among the most frequently disposed of pharmaceuticals in medical facilities. Worldwide, Ceftriaxone is found to be the most frequently used antibiotic, followed by Penicillins (46.9%) and Cephalosporins (44.7%) (Momanyi et al., 2019). A study at the Rift Valley General Hospital showed that Benzyl penicillin (52.0%) was the most administered penicillin, Ceftriaxone (91.0%) was the most administered cephalosporin, and Metronidazole was the third most used antibiotic (Momanyi et al., 2019). The improper disposal of these antibiotics increases the risk of their migration into water sources, potentially leading to widespread environmental contamination. Antibiotics also interfere with water treatment processes since most depend on biodegradation, and significantly affect non-target organisms, both human beings and aquatic life, with exposure potentially causing antibiotic resistance in humans (Orina, 2018).

Incineration is widely recognised as the safest and most effective form of pharmaceutical waste treatment because it does not harm the environment or public health in general (WHO, 1999). The process involves high-temperature combustion of between 800°C and 950°C, capable of reducing both organic and combustible waste to inorganic, incombustible matter, significantly reducing waste in both volume and weight (Mazzei & Specchia, 2023). The majority of health and monitoring organisations, including the United Nations and the World Health Organisation, advise incineration for the disposal of unwanted pharmaceuticals, including unit dose repacks, used vials, used syringes, IV preparations, discontinued preparations, expired pharmaceuticals, and personal medications (Smith et al., 2008). The Environmental Protection Agency of the United States has similarly recommended incineration for pharmaceuticals as the best demonstrated available technology for their complete destruction (Shukla et al., 2017).

Despite the widespread recommendation of incineration, there remains a critical knowledge gap concerning the safety of the resultant ash before it is released into the environment. According to a study done by Githinji et al (2024), some of the substances remain unchanged during incineration and become part of bottom ash. Many healthcare facilities have incinerators, but few of them are able to attain the recommended temperature of 3000°C. The Kenya Medical Research and Training Institute (KEMRI) is the only institution with incinerators that operate at 3000°C. The incinerators at Kenyatta National Hospital (KNH) and Moi Teaching and Referral Hospital operate at temperatures ranging from 700 to 800 degrees Celsius. This results in combustion efficiency (CE) of between 48 per cent and 61 per cent (Mazzei & Specchia, 2023).

To achieve efficient operation of the incineration process, there needs to be adequate operator training and appropriate storage and ash disposal facilities (Mazzei & Specchia, 2023). The primary system components utilised in the incineration of medical waste are combustion chambers, a bottom ash removal system, and gas cleaning equipment (Santoleri, 2009). A study carried out in 12 incinerator facilities in Nairobi revealed that incinerator ash is mainly disposed of in an open dumpsite (Koros, 2009). Furthermore, in this study, other objectives in the same study area indicated that the final ash from the medical facilities' incinerators is disposed of in a hilly dumpsite (Orina et al., 2023).

Studies done in Kenya concerning river water and wastewater have indicated the presence of pharmaceutical chemicals in collected samples (Muriuki et al., 2020); however, most of these studies have paid little attention to the sources of antibiotics in those environments, concentrating instead on their detection in wastewater and river water rather than on what has caused their presence. There is insufficient data on the presence of pharmaceutical waste in ash from incinerators. Consequently, this study examined the ashes from incinerators in medical facilities in Nakuru Town for the presence of Metronidazole, Benzyl penicillin, and Ceftriaxone, the three most commonly used antibiotics in the study area (Momanyi et al., 2019), to assess whether incineration effectively eliminates antibiotic residues before the ash is released into the environment.

2.0 LITERATURE REVIEW

Pharmaceutical Waste and Incineration

Pharmaceuticals are critical in maintaining people's health and improving the quality of life for millions, but not all dispensed pharmaceuticals are consumed (Bain, 2010). Pharmaceutical waste in hospitals mainly consists of unused or partially used drug products, spilt, withdrawn, recalled, contaminated or patient medications that have expired and those with no precise expiry dates. All healthcare facilities are approximately capable of generating 3 per cent of pharmaceutical waste (WHO, 2011). In the US, it is estimated that 1/3 of the prescribed drugs become pharmaceutical waste (Product Stewardship Institute, 2018). On the other hand, in France, pharmaceutical waste is estimated to be approximately 17,600 t/year – 260g per capita in 2018 (Cyclamed, 2018). The percentages of unused medications that have expired and those without a specified expiration date were 32.7 per cent, 17.7 per cent, and 11 per cent in Palestinian hospitals. In a Dar es Salaam tertiary hospital, pharmaceutical waste was examined. The results revealed that 730 medicine dosages were wasted (Kagashe et al., 2011).

Effective handling of pharmaceutical waste is crucial for mitigating the risks linked to its disposal. The World Health Organisation emphasises the significance of proper pharmaceutical waste management and has developed clear guidelines for its disposal (Prüss-Üstün et al., 1999). Pharmaceutical waste management entails gathering, packing, storing, sorting, transporting, treating, and disposing of waste (Rushton, 2003).

Frequently used drugs in Kenya are antiretrovirals, antimalarials, and antibiotics. In Kenya, the use of antibiotics is essential for healthcare provision. Sadly, there is also a high level of misuse of them. As a result, drug-resistant bacterial strains have emerged (Okoth et al., 2018). The three antibiotics were selected since, according to the study carried out in the study area on antibiotic use, it showed that Ceftriaxone had the highest percentage of use, followed by Benzyl penicillin (29.0%) and metronidazole (25.1%) (Momanyi et al., 2019).

There was no established method for handling pharmaceutical waste on a global scale. Appropriate handling, treatment, disposal, segregation, and quantification of waste generated are critical in reducing improper pharmaceutical waste. However, incineration is the most recommended method of disposal since it involves both treatment and sanitisation of pharmaceutical waste through a high-temperature and dry oxidation procedure that is capable of reducing both organic and combustible waste to inorganic waste, with incombustible matter also reduced significantly in both volume and weight (Mazzei & Specchia, 2023). Up to 95 per cent of the waste's weight and volume are reduced during the incineration process (Ngari et al., 2011). According to WHO (1999), incineration is the safest and most effective form of treatment because it does not harm the environment or public health in general. Therefore, the majority of health and monitoring organisations, such as the United Nations and WHO, advise the procedure. Smith et al. (2008) advise burning unwanted pharmaceuticals, including unit dose repacks, used vials, used syringes, IV preparations, discontinued preparations, expired pharmaceuticals, and personal medications. The best method of destroying pharmaceuticals that is friendly to the environment is incineration at high temperatures with flue gas cleaning (WHO, 1999).

Incineration Practices in Kenya

Although several healthcare institutions have incinerators, few of them are able to attain the recommended temperature of 3,000°C. The Kenya Medical Research and Training Institute (KEMRI) is the only organisation with incinerators that operate at 3,000°C. The incinerators at Kenyatta National Hospital and Moi Teaching and Referral Hospital run at temperatures ranging from 700 to 800 degrees Celsius, resulting in combustion efficiency of between 48 per cent and 61 per cent (Nyaga et al., 2020). In Kenya, the majority of healthcare facilities feature 300°C brick and mortar incinerators. UNICEF has encouraged the use of inexpensive, on-site incinerators for controlled air combustion in poor nations. Kenya is among the nations that have adopted these two-chamber brick incinerators, which were created by De Montfort University professor Jim Picken (WHO, 2004). They may reach temperatures of roughly 800°C when kept in good condition, which destroys waste and lowers the formation and emission of dioxins and furans in ash and gases.

Antibiotics Selected for the Study

The three antibiotics selected for this study were Metronidazole, Benzyl penicillin, and Ceftriaxone, as they were the most commonly used antibiotics in the study area. Ceftriaxone was found to be the most prevalent used antibiotic worldwide (Atwerp University). In Kenya, penicillins were found to be the most commonly used class of antibiotics between 1997 and 2001 (Mitema & Kikuvi, 2004). The three antibiotics were selected since, according to the study carried out in the study area on antibiotic use, Ceftriaxone had the highest percentage of use, followed by Benzyl penicillin (29.0%) and Metronidazole (25.1%) (Momanyi et al., 2019). A study at the Rift Valley General Hospital showed that Benzyl penicillin (52.0%) was the most administered penicillin and Ceftriaxone (91.0%) was the most administered cephalosporin (Momanyi et al., 2019).

Certain antibiotics, like penicillin, break down quickly, but other antibiotics, like fluoroquinolones and tetracyclines, are much more persistent, staying in the environment for longer periods of time, travelling farther, and building up to greater concentrations (Larsson, 2014). According to Gullberg et al. (2011), antibiotics are pollutants to the environment since their existence, even in low amounts, promotes the growth of antibiotic-resistant bacteria. They directly impact nitrogen transformation, sulphate reduction, decomposition of organic matter, nutrient cycling, and environmental methanogenesis (Bielen et al., 2017).

Minimum Inhibitory Concentrations as a Reference Standard

The term minimum inhibitory concentration (MIC) refers to the in vitro thresholds at which particular bacterial strains become susceptible or resistant to an antibiotic (Kowalska-Krochmal & Dudek-Wicher, 2021). Pollution from pharmaceutical manufacturing facilities is typically connected to environmental concentrations that are near to or higher than the minimal inhibitory concentrations of specific antibiotics in certain cases (Larsson, 2014). However, Schuster et al. (2022) have noted that antibiotic concentrations below minimum inhibitory concentrations have the ability to favour resistant bacteria. The relationship between antibiotic concentrations and the presence of antibiotic resistance genes in environmental samples is evident (Yang et al., 2014). The majority of sampling sites in previous studies had traces of the selected antibiotics in very high concentrations that exceeded the CLSI minimal inhibitory concentrations, which is the vital reference recommended by the UN and WHO (Orina et al., 2023).

World Health Organisation (2025) emphasises that incinerator ash from pharmaceutical wastes is regarded as hazardous waste since it may contain residual toxic metals, persistent organic pollutants, and incompletely combusted compounds, especially in cases where incineration temperatures and combustion conditions are not sufficient. Even if incinerator ash needs special disposal, individual countries treat and dispose of the final incinerator ash differently, as shown in the table below.

Table 1: Comparative of Final Ash Management

Country/Region	Final Ash Management
Germany	Stabilization and disposal in underground hazardous repositories (EU, 2019)
France	Cement/lime stabilization followed by engineered hazardous landfill disposal (Astrup, 2008)
United States	TCLP testing followed by secure hazardous landfill disposal under RCRA (USEPA, 2024)
Canada	Stabilization and disposal in licensed hazardous waste landfills (CCME, 2006).
China	Stabilization; hazardous landfill; increasing use of cement kiln co-processing (MEE, 2021)
European Union	Stabilization/encapsulation and disposal in hazardous landfills or monofills (European Commission, 2019)
WHO recommendation	Hazardous landfill, encapsulation, monofills, or concrete-lined ash pits (World Health Organization, 2025)

In Kenya, most studies revealed improper disposal of incinerator ash. This is evident in a study carried out in 12 incinerator facilities in Nairobi, which indicated that incinerator ash is mainly disposed of in an open dumpsite (Koros, 2009). Equally, in this study, other objectives in the same study area indicated that the final ash from the incinerator used by medical facilities is disposed of in a hilly dumpsite (Orina et. al., 2023). Improper disposal of incinerator ash might lead to the presence of pharmaceuticals in the environment. Hence, this practice can be linked to antimicrobial resistance, the risk of aquatic or wildlife poisoning, accidental poisoning and abuse, and the waste of health care incomes and missed chances for medical treatment (Freita & Radis-Baptista, 2021).

3.0 METHODOLOGY

The study was conducted in Nakuru City, located in Nakuru County, 160 km northwest of Nairobi, in the Great Rift Valley at an elevation of 1,859 metres above sea level. Nakuru City is the fourth-largest urban centre in Kenya after Nairobi, Mombasa, and Kisumu. The city is located in an environmentally sensitive area (Mwangi, 2000).

A longitudinal research design was adopted since ash samples were collected repeatedly over a three-week period at Lakey Hospital and Rifty Hospital, which were selected as sampling sites because they had functional incinerators used for pharmaceutical waste disposal. Fly ash from the chimney of Rifty Hospital was additionally collected to assess antibiotic residues in incineration emissions. This was done to capture short-term temporal variations in antibiotic residues resulting from routine healthcare waste incineration and disposal practices in medical facilities. A three-week sampling period was considered because the medical facilities receive continuous deposits of incinerator ash from hospitals, allowing repeated sampling of fresh ash generated under normal operating conditions. A total of nine ash samples of one kilogram each were collected from the sampling point over the three weeks, with sampling conducted once weekly from both hospital incinerators. Samples were gathered by scooping small quantities of ash material from different points of the ash heap incinerator chimney using a stainless-steel spade and preparing them for analysis. The samples were fully packaged in one-kilogram zip lock bags and shipped to the laboratory for analysis. All reagents used were of high purity, sourced from Sigma-Aldrich Kenya, while Metronidazole, Benzyl penicillin, and Ceftriaxone standards were purchased from Merck Millipore Company. Precision was achieved by ensuring that the standard solution was prepared to be used as a reference. Each standard solution was then injected, and its readings were recorded. To ensure robustness, a minimum of five determinations were conducted for each set of measurements, addressing both intra-assay precision (within a set of measurements) and intermediate precision (across different sets of measurements). To maintain accuracy, one of each standard solution was prepared to test the method's accuracy. Two sets of samples of each sample ash (spiked and unspiked) in three different concentrations, that is, 80 per cent, 100 per cent, and 120 per cent the 100 per cent concentration were prepared as specified in the analytical method.

Before extraction, samples were centrifuged for 4 minutes at 4,000 rpm to eliminate suspended particles and subsequently maintained at 4°C until the Solid Phase Extraction stages. The samples were filtered with 0.45 µm nylon filters before analysis.

The determination of antibiotic compounds in the incinerator ashes was carried out using Waters High-Performance Liquid Chromatography (HPLC) on a Shimadzu Nexera with RP-C8 and C18 columns. The determination of metronidazole was analysed using a Shimadzu LC – 2OAD XR High-Performance Liquid Chromatography (HPLC) system equipped with a UV detector UV 316nm, column 4.6 mm x 15 cm; 5- µm packing L1, Column temperature of 30 degrees. The solution was prepared as 0.1 per cent (v/v) glacial acid in water, and the mobile phase solution was prepared from a mixture of acetonitrile and solution A (40:60). The mobile phase was delivered at a flow rate of 1.0 mL/min, with a 5 µL injection volume used for metronidazole analysis.

Benzyl penicillin was analysed using HPLC of Shimadzu make and model LC-2OAD XR was used with the detector UV 220 nm, Column 4.6-mm x10-cm; 5- µm packing L1, Column temperature of 30°C. Solution A

was prepared as 0.01 M monobasic potassium phosphate in water and mobile phase methanol, and solution A (40:60) was prepared.

On the other hand, ceftriaxone was analysed using the UV detector at 270 nm, column 4.0 mm x 15 cm; 5-µm packing L1. An isocratic mobile phase comprising 0.01 M monobasic potassium phosphate in water and methanol at a ratio of 40:60 (v/v) was used. The mobile phase was delivered at a constant flow rate of 1.0 mL/min, with detection set at 220 nm.

Descriptive and inferential statistical methods were employed to analyse the data. A two-way ANOVA was conducted to assess variations in antibiotic concentrations across sampling sites and antibiotic types, with concentrations reported in µg/mL. The researcher received ethical approval from the Ministry of Health and NACOSTI prior to data collection.

4.0 FINDINGS AND DISCUSSION

Antibiotic Concentrations in Incinerator Ash

The laboratory analysis of incinerator ash samples collected from Lakey Hospital and Rifty Hospital revealed the presence of antibiotic residues in very high concentrations.

Table 2: Comparison of Antibiotic Concentrations in Different Sampling Sites

Descriptive Statistics				
Dependent Variable: Concentration µg/ml				
Antibiotic	**Sampling site**	**Mean N**	**Std. Deviation**	**N**
Benzyl penicillin	Hilly dumpsite	11624.0800	10226.69935	3
	Lakey Hospital	24111.5100	3103.19597	3
	Rifty Hospital	1281.0800	258.58797	3
	Total	12338.8900	11251.14570	9
Ceftriaxone	Hilly dumpsite	12816.9567	14472.04320	3
	Lakey Hospital	192944.2667	67662.69247	3
	Rifty Hospital	5049.7067	3243.69691	3
	Total	70270.3100	98365.99182	9
Metronidazole	Hilly dumpsite	.0000	.00000	3
	Lakey Hospital	.0000	.00000	3
	Rifty Hospital	265.3333	459.57081	3
	Total	88.4444	265.33333	9

The results revealed that ash samples obtained from both Lakey and Rifty Hospital had very high concentrations of both Ceftriaxone and Benzyl penicillin. The mean concentration of Benzyl penicillin in Lakey Hospital incinerator ash was 24,111.51 µg/ml with a standard deviation of 3,103.20, while Rifty Hospital recorded a mean concentration of 1,281.08 µg/ml with a standard deviation of 258.59. Ceftriaxone recorded the highest concentrations across all sampling sites, with Lakey Hospital recording a mean concentration of 192,944.27 µg/ml with a standard deviation of 67,662.69, while Rifty Hospital recorded a mean concentration of 5,049.70 µg/ml with a standard deviation of 3,243.70. Metronidazole was absent in Lakey Hospital incinerator ash but was present in Rifty Hospital at a mean concentration of

265.33 µg/ml with a standard deviation of 459.57. These findings indicate that the incineration process at both facilities was largely ineffective in eliminating antibiotic residues from pharmaceutical waste.

The absence of Metronidazole in Lakey Hospital ash and its presence in small concentrations in Rifty Hospital may be attributed to the form in which the antibiotic is used. Metronidazole is mostly used in tablet form and mostly administered for outpatients, which is likely to influence its presence in medical facility incinerators (Orina et al., 2023). The significantly higher concentrations of Ceftriaxone and Benzyl penicillin in Lakey Hospital compared to Rifty Hospital may be mainly due to the high use of Ceftriaxone in Lakey medical facility, as well as incomplete incineration that was observed during sampling. As shown in Figure 1, the contents in the incinerator pit at Lakey Hospital were ready for disposal to Hilly dumpsite and considered to be final ash, yet bottles that had not been destroyed by the incineration process were still visible, with the majority having contents inside.



Figure 1: An Incinerator at Lakey Sampling Site

This is consistent with findings by Padmanabhan and Barik (2019), who noted that inefficient incinerators would not be able to destroy unwanted antibiotics, hence releasing them to the environment, as they assume they are safe since incineration is the recommended method of disposing of unwanted pharmaceuticals.

Statistical Differences in Concentrations between Sampling Sites

A two-way ANOVA was conducted to compare antibiotic concentrations between sampling sites.

Table 3: Tests of between-Subjects Effects (Different Sampling Sites)

Tests of Between-Subjects Effects					
Dependent Variable: Concentration					
Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Corrected Model	93889677829.690[a]	8	11736209728.711	21.501	.000
Intercept	20516701189.979	1	20516701189.979	37.586	.000
Antibiotic	25294851277.152	2	12647425638.576	23.170	.000
Sampling site	27237382066.786	2	13618691033.393	24.949	.000
Antibiotic * Sampling site	41357444485.751	4	10339361121.438	18.942	.000
Error	9825389667.848	18	545854981.547		
Total	124231768687.517	27			
Corrected Total	103715067497.538	26			

a. R Squared = .905 (Adjusted R Squared = .863)

A statistically significant variation in mean antibiotic concentrations was observed among the sampling sites, $F(4, 18) = 18.942$, $p < .001$. The R-squared value of 0.905 indicated that 90.5 per cent of the variance in antibiotic concentration was explained by the model, suggesting a strong relationship between the sampling site, antibiotic type, and the resulting concentration. These findings suggest that the type of antibiotic used influences the concentration of antibiotics in ash, possibly due to differences in their chemical properties or degradation rates.

Pairwise comparisons between sampling sites revealed that the mean difference between Hilly dumpsite and Lakey Hospital was statistically significant at the 0.05 level [Mean Difference = -64,204.913, p = 0.000].

Similarly, the mean difference between Lakey Hospital and Rifty Hospital was statistically significant [Mean Difference = 70,153.219, p = 0.000]. However, the mean difference between Hilly dumpsite and Rifty Hospital was not statistically significant [Mean Difference = 5,948.306, p = 0.596]. These findings indicate that Lakey Hospital had significantly higher antibiotic concentrations in its incinerator ash compared to both Rifty Hospital and Hilly dumpsite, underscoring the variability in incineration effectiveness across different medical facilities.

Statistical Differences in Concentrations across Different Antibiotics

Tukey's range test was utilised to compare the pairs of means between different antibiotic types.

Table 4: Pairwise comparisons of antibiotic concentrations lower bound

Pairwise Comparisons					
Dependent Variable: Concentration					
(I) Antibiotic	**(J) Antibiotic**	**Mean Difference (I-J)**	**Std. Error**	**Sig.b**	**95% Confidence Interval for Difference b**
					Lower Bound
Benzyl penicillin	Ceftriaxone	-57931.420*	11013.678	.000	-81070.299
	Metronidazole	12250.446	11013.678	.281	-10888.434
Ceftriaxone	Benzyl penicillin	57931.420*	11013.678	.000	34792.541
	Metronidazole	70181.866*	11013.678	.000	47042.986
Metronidazole	Benzyl penicillin	-12250.446	11013.678	.281	-35389.325
	Ceftriaxone	-70181.866*	11013.678	.000	-93320.745

Table 5: Pairwise Comparisons of Antibiotic Concentrations Upper Bound

Pairwise Comparisons		
Dependent Variable: Concentration		
(I) Antibiotic	**(J) Antibiotic**	**95% Confidence Interval for Difference**
		Upper Bound
Benzyl penicillin	Ceftriaxone	-34792.541
	Metronidazole	35389.325
Ceftriaxone	Benzyl penicillin	81070.299
	Metronidazole	93320.745
Metronidazole	Benzyl penicillin	10888.434
	Ceftriaxone	-47042.986

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

The results revealed that the mean difference between Ceftriaxone and Benzyl penicillin was statistically significant at the 0.05 level [Mean Difference = 57,931.420, p = 0.000]. Similarly, the mean difference between Ceftriaxone and Metronidazole was statistically significant [Mean Difference = 70,181.866, p = 0.000]. However, the mean difference between Benzyl penicillin and Metronidazole was not statistically significant [Mean Difference = 12,250.446, p = 0.281]. These variations in antibiotic concentrations between different pairs could be attributed to their chemical properties, incineration temperatures, incineration duration, and quantities generated as waste. Incineration temperatures and duration might affect the concentration since different antibiotics have different chemical properties and hence might be destroyed by the incineration process at different temperatures and durations of incineration (Orina et al., 2023).

Antibiotic Concentrations in Fly Ash from Incinerator Chimney

Analysis of fly ash from the incinerator chimney, which was only conducted at Rifty Hospital, revealed the presence of Ceftriaxone and Benzyl penicillin in samples taken.

Table 6: Minimal Inhibitory Concentrations Breakpoints

	Interpretive Categories and MIC Breakpoints µg/ml			Lakey	Rifty	Hilly	Fly Ash
	S	I	R	Conce	Conce	Conce	Conce
Benzyl penicillin	≤0.06	0.12-1	≥2	24111	1281	11624	588.9
Metronidazole	≤8	16	≥32	0.000	265	0.000	0.000
Ceftriaxone	≤1	2	≥4	192944	5049	12816	273.5

Source: Humphries et al. (2021)

Benzyl penicillin had a concentration of 588.9 µg/ml, and Ceftriaxone had a concentration of 273.5 µg/ml. Some antibiotics are volatile and hence could be detected in fly ash. This finding underscores the need for rigorous air quality monitoring and emission control measures within the incineration process. The presence of fly ash is dangerous to both humans and the environment if further treatment is not done, as bottom ash is considered less harmful than fly ash since it is reported to be less contaminated with heavy metals (Esilaba et al., 2020). Furthermore, the presence of specific heavy metals in fly ash, which can include elements like lead, mercury, or cadmium, carries significant environmental and human health implications, with their potential to bioaccumulate and persist in ecosystems leading to long-term ecological disruptions (Esilaba et al., 2020).

Comparison with Minimal Inhibitory Concentration Breakpoints

The findings indicated that concentrations of the present antibiotics in both incinerator ash sampling sites exceeded the CLSI minimal inhibitory concentration breakpoints. The CLSI breakpoints for Benzyl penicillin are susceptible at ≤0.06 µg/ml, intermediate at 0.12-1 µg/ml, and resistant at ≥2 µg/ml. For Ceftriaxone, the breakpoints are susceptible at ≤1 µg/ml, intermediate at 2 µg/ml, and resistant at ≥4 µg/ml. For Metronidazole, the breakpoints are susceptible at ≤8 µg/ml, intermediate at 16 µg/ml, and resistant at ≥32 µg/ml. All detected concentrations in the incinerator ashes of both Lakey and Rifty hospitals substantially exceeded these breakpoints, indicating that the ash released into the environment contains very high concentrations of antibiotics that are likely to promote their presence in the environment, which is undesirable due to their impact on human health and aquatic life when exposed (Orina et al., 2023).

Other studies where high concentrations of antibiotics have been found were conducted in China, India, Israel, Korea, and the USA in industrial effluents (Larsson, 2014; WHO, 2014). These findings are consistent with the present study, which demonstrates that antibiotics are released into the environment even after undergoing an incomplete incineration process, which is the most recommended method of pharmaceutical waste disposal. This might also be due to inefficient incinerators. The condition of the incinerator can affect the concentration of antibiotics in the ash, and perhaps the incineration in Rifty Hospital is comparatively better and closer to the recommended standards than that of Lakey Hospital. If the incinerators are not effective, they will not be able to destroy the unwanted antibiotics, hence releasing them to the environment while assuming they are safe since incineration is the recommended method of disposing of unwanted pharmaceuticals (Padmanabhan & Barik, 2019).

Implications for Environmental Safety and Antimicrobial Resistance

The findings of this study have significant implications for environmental safety and antimicrobial resistance. The incinerator ash collected after incineration in the study area is disposed of at Hilly

dumpsite, which is an open dumpsite, since it is assumed to be safe following incineration. However, from the laboratory analysis results, the ash after incineration is not safe since it shows very high concentrations of antibiotics. Once in the environment, these substances have the ability to harm populations, communities, and ecosystems by acting on non-target organisms including plants, animals, and microorganisms. Improper disposal of pharmaceutical waste, especially antibiotics, can contribute to the proliferation of antimicrobial resistance. Residues released into the environment can potentially expose non-target organisms to sublethal doses of antibiotics, fostering the development of resistance among microbial populations (Orina et al., 2023). This scenario underscores the urgency of not only proper waste disposal but also comprehensive strategies to combat the growing threat of antimicrobial resistance.

5.0 CONCLUSION AND RECOMMENDATIONS

Conclusion: This study analysed incinerator ashes from two medical facilities in Nakuru Town, Kenya, namely Lakey Hospital and Rifty Hospital, to determine the concentrations of Metronidazole, Benzyl penicillin, and Ceftriaxone before the ash was released into the environment. The findings revealed that the incineration process at both facilities was largely ineffective in eliminating antibiotic residues from pharmaceutical waste. The mean concentrations of Benzyl penicillin in Lakey Hospital and Rifty Hospital incinerator ashes were 24,111.51 µg/ml and 1,281.08 µg/ml, respectively, while Ceftriaxone concentrations were 192,944.27 µg/ml and 5,049.70 µg/ml, respectively. Metronidazole was absent in Lakey Hospital ash but recorded at 265.33 µg/ml in Rifty Hospital. The concentrations of all detected antibiotics exceeded the CLSI minimum inhibitory concentration breakpoints by considerable margins, suggesting that ash released from both facilities contains high antibiotic residues with potential implications for environmental and public health.

The study further revealed that fly ash from the incinerator chimney of Rifty Hospital contained Benzyl penicillin at 588.9 µg/ml and Ceftriaxone at 273.5 µg/ml, underscoring the need for rigorous air quality monitoring and emission control measures within the incineration process. The significant variability in antibiotic concentrations between the two facilities, with Lakey Hospital recording considerably higher concentrations than Rifty Hospital, suggests that the effectiveness of incineration varies across facilities, likely due to differences in incinerator condition, operating temperatures, and waste composition. The incinerator ash collected after incineration in the study area is disposed of at Hilly dumpsite, which is an open dumpsite, since it is assumed to be safe following incineration. However, the laboratory analysis results demonstrate that the ash after incineration is not safe, as it contains very high concentrations of antibiotics that have the potential to contaminate the surrounding environment. The findings emphasise the need for enhanced incineration procedures, appropriate ash disposal practices, and stringent regulatory oversight prior to environmental release.

Recommendations: Based on the findings of this study, it was revealed that even after using incineration as the most recommended method of medical waste disposal, there can still be the presence of pharmaceuticals in the final ash. Hence, some incineration processes can be ineffective due to reasons such as inadequate operating temperatures. Thus, the study recommends the need for surveillance and regular inspection of incinerators in medical facilities to ensure their effectiveness, since there are still traces of antibiotics even after incineration, which is the most recommended method of disposal. Regulatory bodies and healthcare institutions should collaborate in ensuring the implementation of available guidelines and standard procedures for handling this type of waste. There is a need for proper disposal of the final ash, such as the use of sanitary landfills, to protect the environment from pollution

arising from antibiotic residues in incinerator ash. To ensure the safety of incinerator ash before release to the environment, regulatory bodies, healthcare institutions, and environmental agencies should collaborate to oversee regular testing of the final ash and evaluate the implementation of proper handling and disposal procedures before it is released into the environment. There is also a need for capacity building of pharmaceutical waste handlers and creation of awareness of the impacts of improper disposal of pharmaceutical waste. Furthermore, future studies could be done to explore the efficiency of incineration processes in medical facilities across the country, considering factors such as temperature, duration, and waste composition.

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