



Characterization of Medical Wastes Incinerator Ashes from the Medical City Complex in Baghdad and Implications for Environmental and Public Health

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ABSTRACT

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Medical wastes generated from various medical processes such as diagnosis, treatment, and research in human and veterinary medicine, pose significant environmental and public health risks if improperly managed. This study investigates the inefficiencies of medical wastes incineration at the Medical City Complex in Baghdad and their role in heavy metal contamination. The core objective is to examine the direct links between incinerator inefficiency and elevated levels of heavy metals in incinerator ash. Concentrations of cadmium (4.88–0.85 ppm), chromium (44.19–21.31 ppm), lead (7.01–2.33 ppm), silver (13.38–4.08 ppm), and arsenic (4.88–0.85 ppm) in bottom ash were found to exceed permissible limits, contributing to significant soil and groundwater pollution surrounding the landfill sites. This study represents the first systematic analysis of medical waste incineration in Baghdad, highlighting the critical need for improvements in waste management practices. The findings emphasize the urgent need for better incineration technology, proper disposal of medical waste, and regular monitoring to reduce the area's environmental and public health hazards.

1. INTRODUCTION

Medical wastes, also known as health care wastes (HCW) or clinical waste, refers to all types of waste generated from various medical activities, including diagnosis, treatment, and research in both human and veterinary medicine. HCW includes wastes produced in medical institutions, research facilities, and laboratories [1]. The World Health Organization (WHO) uses the term HCW to encompass this broad range of medical wastes. However, there is no globally agreed-upon definition of medical waste, and the terminology can vary across countries and regions [2]. Generally, medical infectious waste is considered a subset of HCW that is generated in healthcare facilities and is unsuitable for disposal with municipal solid waste (MSW) [3]. This is because medical infectious waste can contain pathogens and therefore requires special handling to prevent the spread of diseases. HCW is considered one of the most hazardous types of waste, second only to radioactive waste. It is typically collected separately within hospitals and treated separately from MSW in dedicated treatment facilities. Hospitals generate around 50% of medical waste, while the rest comes from other healthcare facilities like clinics, with dialysis units being the largest producers of HCW [4]. According to the WHO, medical wastes can be broadly categorized based on their level of hazard. Approximately 80% of total healthcare waste is considered non-hazardous. Around 15% of healthcare waste is classified as infectious or pathological in nature. The remaining 5% includes sharps, toxic chemicals,

pharmaceutical waste, and radioactive waste. Looking more closely at the breakdown of hazardous medical waste sharps, such as needles and scalpels, make up around 1% of the total. Chemical or pharmaceutical waste accounts for about 3% of healthcare waste. Less than 1% is classified as other hazardous waste, including radioactive or cytostatic materials [5]. Incineration is a high-temperature thermal process that can effectively destroy microorganisms and hazardous materials in medical waste. The objectives are volume reduction, removal of volatile and combustible substances, and destruction of toxic and pathogenic materials. Key requirements include sufficient oxygen, turbulence, proper temperature (900–1200°C), long residence time (>2-3 seconds), rapid cooling to prevent toxic by-products, and flue gas cleaning. The incinerator site must be carefully selected to ensure the resulting air emissions do not degrade air quality for nearby residents [6]. Medical wastes incinerator fly ash (MWIFA) is a hazardous waste by-product that represents 3-5% of the original waste, with high dioxin concentrations, leachable alkali chlorides, carbon materials, and heavy metals representing more than 80% of the total incinerator. The complex nature of MWIFA due to its high chlorine and carbon content makes it more difficult to treat compared to municipal solid waste (MSW) incinerator fly ash [7]. Traditional treatment techniques for MSW incinerator fly ash include separation, solidification/stabilization, and thermal methods, all aimed at removing or immobilizing heavy metals. Other researchers have also investigated decomposition/degradation of dioxins in MSWIFA via different thermochemical

approaches. However, these methods may not be directly applicable to MWIFA because it has a different composition [8].

Henceforth, novel effective technologies need to be developed specifically for the treatment and detoxification of MWIFA. The presence of huge amounts of toxic constituents in MWIFA highlights the importance of finding appropriate treatments that can go along with environmental and health risks associated with this type of medical waste [9]. Iraq has faced significant challenges in waste management for decades. According to statistics from the Baghdad municipality, the city generates an estimated 10,000-11,000 tons of solid waste daily, with about 7,000 tons deposited in landfills and the remaining 5,000 tons in unsanitary or random locations. In 2007, the Iraqi government developed a national solid waste management plan, but it was never fully adopted. Waste management remains one of the country's most serious environmental and health problems. While a recent bill on waste management was proposed in the Iraqi Parliament, it was never approved. The situation is particularly dire for medical wastes management. A government report indicates that medical waste management in Iraq is very poor and requires extensive reform. As of 2019, there are 280 public and private hospitals in Iraq, with 91 located in Baghdad. The total medical waste generated by these institutions is approximately 1,902 tons [10]. Medical wastes are collected separately and transported to incineration sites, where it is processed at temperatures between 400-1,000°C. The incineration process achieves a volume reduction of 95% and a mass reduction of 75%, with the remaining ash transferred to landfills sites. However, the overall medical wastes management system in Iraq remains inadequate and in need of significant improvement [11].

This study aims to investigate the facts about the medical waste management process in the Medical City Complex in Baghdad, which is considered the largest medical complex in Iraq. The study includes documenting the activities related to medical waste management from its generation until its final fate, including the efficiency and outputs of the incinerators used to treat this waste, in addition to the effect of pollutant concentration in the resulting ash, in addition to its effect on soil and groundwater.

2. MATERIALS AND METHODS

2.1 The research area

The research area, the Medical City Complex, was selected because it is the largest health care provider in the capital city of Baghdad. The complex was built before the establishment of the Iraqi Ministry of Environment in 2003, and therefore, it does not have the necessary environmental approvals. Based on visits by monitoring teams from the Ministry of Environment and citizen complaints, the complex has been identified as a source of environmental pollution.

Baghdad Teaching Hospital is a major medical facility that opened in 1970 with a capacity of 1,200 beds. It provides a wide range of diagnostic, therapeutic, medical, surgical, and educational services across various medical specialties. The hospital includes clinics for skin, multiple sclerosis, osteochondrosis, hematology, oncology, physiotherapy, and family planning. It employs 189 doctors and 302 postgraduate doctors, and sees around 26,883 outpatient visits per month and performs 380 operations per month.

The Specialized Surgery Hospital opened in 1984 with a capacity of 664 beds. It specializes in providing diagnostic, therapeutic, medical, surgical, and educational services across various surgical departments, including urology, kidney transplant, ENT, orthopedics, thoracic and vascular surgery, ophthalmology, plastic surgery, and neurosurgery. The hospital employs 92 specialist doctors and 306 postgraduate doctors, and sees around 1,500 inpatients per month and performs 700 operations per month.

The Private Nursing Home Hospital opened in 1982 with a capacity of 249 beds. It provides diagnostic, therapeutic, medical, and surgical services across various departments, employing 45 specialist doctors. The hospital sees around 908 inpatients per month and performs 321 operations per month.

The Children's Protection Hospital opened in 1983 with a capacity of 318 beds. It specializes in providing diagnostic, therapeutic, medical, surgical, and dental services for children up to the age of 16, with subspecialties in bone marrow transplant, hematology, oncology, and endocrinology. The hospital employs 38 specialist doctors and 120 students, and sees around 873 inpatients per month.

The Hepatology and Gastroenterology Hospital opened in 1994 with a capacity of 100 beds. It provides diagnostic, therapeutic, medical, and surgical services for gastrointestinal and liver diseases, employing 25 specialist doctors and 20 graduate students. The hospital sees around 325 inpatients per month and performs 36 operations per month.

The hospitals have small waste containers in departments and hallways, which are collected by cleaners and transported to larger containers. The waste is then transported to a landfill site by dedicated vehicles.

2.2 Waste management activities

The hospitals have committees responsible for managing medical waste. They determine the appropriate treatment methods for different waste types, including incineration for most waste except radioactive, compressed, and chemical waste, which require specialized handling. Expired pharmaceutical waste is either returned to the country of origin or incinerated.

The hospitals do not accurately weigh the medical wastes, but instead estimate the quantities. This indicates a lack of rigorous waste management practices. Table 1 shows the approximate weights of medical waste generated at each hospital, with the Baghdad Teaching Hospital producing the most waste.

The waste quantities can be used to estimate the size and number of storage containers needed, as well as the vehicle capacity required for transport. The data in Table 2 also provides insights into the composition and amounts of different medical waste types, which is important for determining the required treatment capacity.

The hospitals have committees overseeing medical waste management, but lack precise measurement and record-keeping practices. The available data on waste quantities and composition can inform improvements to waste storage, transport, and treatment infrastructure.

2.3 Incinerators' information and bottom ash analysis

The location of the hospitals of the Medical City complex in Baghdad governorate is located in the center of densely populated areas.

Table 1. Information about medical wastes in the Medical City facilities

Name of Hospital or Medical Center	Beds Number	Average Medical Wastes Weight (Kg/Day)	Medical Wastes Treatment	Final Wastes Disposal
Baghdad Teaching Hospital	1200	249.4	Incinerator, Autoclave Shredding	landfill
Specialized Surgery Hospital	664	227.25	Incinerator, Autoclave Shredding	landfill
Private Nursing Home Hospital	249	190	Incinerator, Autoclave Shredding	landfill
Children's Protection Hospital	318	139.3	Incinerator, Autoclave Shredding	landfill
Hepatology and Gastroenterology Hospital	100	56	Incinerator, Autoclave Shredding	landfill
Teaching laboratory hospital	40	33	Incinerator, Autoclave Shredding	landfill
Iraqi Center for Cardiology	20	14	Incinerator, Autoclave Shredding	landfill
Hematology Center	33	12	Incinerator, Autoclave Shredding	landfill
Total	2624	920.95		

Table 2. Type and average quantity of medical wastes

Name of Hospital or Medical Center	Infectious Waste (Kg/Day)	Sharp Waste (Kg/Day)	Pharmaceutical Waste (Kg/Day)	Pathological Waste (Kg/Day)	Chemical Waste (Kg/Day)	Radioactive Waste (Kg/Day)	Pressurized Containers (Kg/Day)
Baghdad Teaching Hospital	165	33	13	30	5	3	0.4
Specialized Surgery Hospital	143	47	11	18	6	2	0.25
Private Nursing Home Hospital	113	40	22	10	3	1	1
Children's Protection Hospital	98	15	19	5	2	0	0.3
Hepatology and Gastroenterology Hospital	27	15	8	4	1	0	1

Table 3. The information of the examine incinerators

Parameters	Incinerator 1	Incinerator 2
Model	BRUUN& SORENSEN AB 400X3 kg/hr	Hoval Sweden
Year of manufacture	1972	1986
Practically burning waste	100 kg/hr	80 kg/hr
Stage number	2	2
Number of the burner	2 primary and secondary stages	3 primary and secondary stages
Combustion design	Vertical Double Chamber	Horizontal-Double Chamber
Temperatures	(400-800)°C (800-1200)°C	(400-600) C (600-800)°C
Fuel type	Diesel	Diesel
The amount of fuel consumed per burner (kg/hr)	30 (kg/hr)	15 (kg/hr)
Chimney height(m)	51 m	8 m
Number of chimneys	1	1
Diameter of the chimney (m)	1 m	0.3 m
Air pollution control devices (APCDs)	Not work	Not work
Loading and de-loading	Manual	Manual
Ash type	Bottom ash	Bottom ash
Type of ash disposal off	Landfill	Landfill

The burning of medical waste in these incinerators on a daily basis creates a danger to public health and the environment such as air pollution in that area as a result of the emission of pollutants from medical waste incinerators which threatens the lives of many people, especially children, the elderly and pregnant women, which causes environmental damage and the Table 3 shows the specifications of those incinerators.

The Incinerator's efficiencies were calculated by the following equation:

$$\text{Incinerator efficiency} = \frac{\text{Generation rate of waste destroyed in the incinerator}}{\text{Generation rate of waste entering the incinerator}} \times 100\%$$

The generation rate of waste destroyed was measured by the weight difference before and after incineration, with calibrated

scales. The generation rate entering was measured before incineration. Random samples were collected for representativeness. Scales and sensors were calibrated regularly, and replicate measurements ensured accuracy with < 2% error margin.

Concerning heavy metal concentration, descriptive statistics were employed to calculate the mean, and standard deviations (SD) of the mean to estimate the centrality tendency and dispersion respectively for all samples. Therefore, confidence intervals (CIs) were also calculated in order to assess the accuracy of the mean concentration estimates. In addition, all the statistical tests were carried out at 0.05 alpha level of significance.

The bottom ash as shown in Figure 1 was collected, and its chemical composition was determined. The Ministry of Science and Technology / Materials Research department analysed heavy metal samples using an atomic absorption spectrometer (Shimadzu, AA-6800). Examining fly ash was impossible because the bag filter was not used in the incinerators.

On the other hands, soil samples taken from the landfill were collected for five months to measure the concentrations of pollutants in the soil for three depths (0, 50, and 100 cm) over different periods. The ashes of medical incinerator waste are buried in a specific place at the municipal landfill site, and the sample was taken from the same landfill site each month.

An atomic flame absorber was used to prepare the soil for laboratory testing. Soil samples were dried and then sieved using a 2 mm sieve to achieve satisfactory homogeneity. Concentrations of heavy metals (Pb, Cd, Ag, As, Cr) in the soil taken from the site for the months (March, April, May, June, and July) for comparison with Iraqi determinants.



Figure 1. Ash generation and collection stages for heavy metals analyzer

3. RESULTS AND DISCUSSION

3.1 Incinerators efficiency

The medical waste management system in the studied area was analyzed based on the provided data. On average, each hospital bed in Iraq generates between 0.5 and 1 kilogram of medical waste per day. This indicates a substantial amount of waste produced by healthcare facilities in the region.

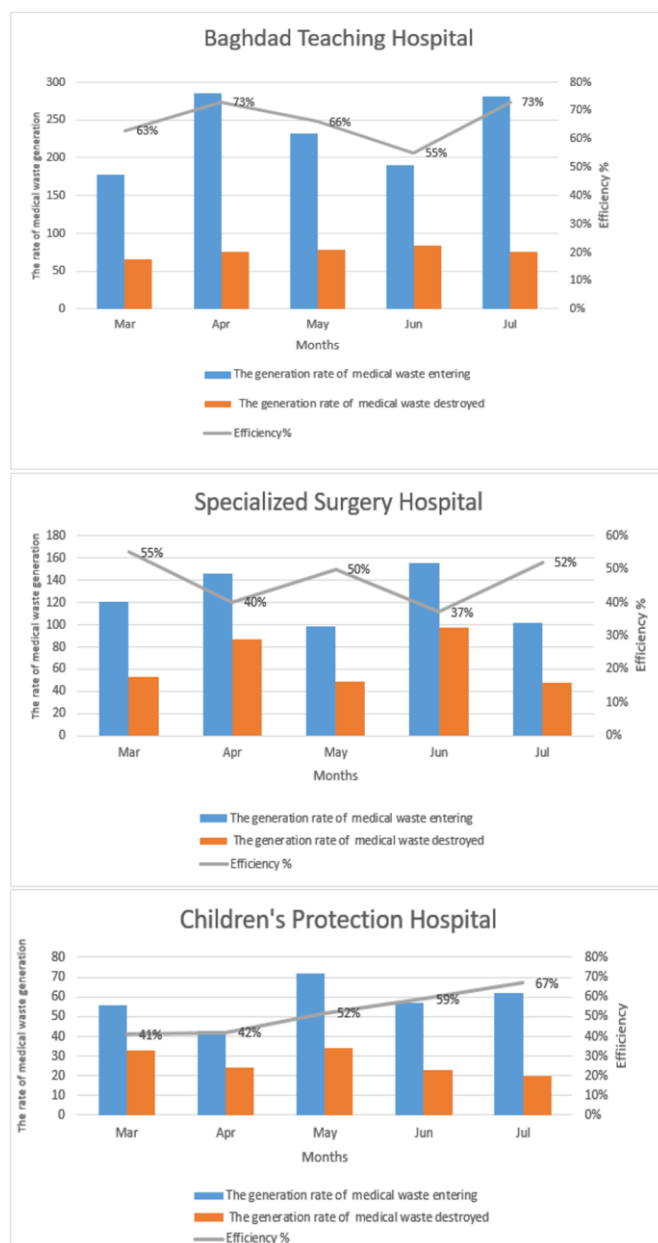
The process of collecting and disposing of medical waste is outsourced to private companies contracted by hospitals. These companies are responsible for transporting the waste from hospitals to incineration facilities. To ensure the safety of their employees, these companies provide essential

protective equipment such as gloves, masks, and uniforms.

Medical waste is collected from hospitals two to three times daily, depending on the hospital's size and waste generation rate. The collected waste is then incinerated in a process that typically lasts between four and eight hours, contingent upon the waste volume. This data was used to create Figure 2, which illustrates incinerator efficiency.

Medical waste is collected after being placed in bags according to its type. The waste collection workers then come to collect it by putting it in special containers. Then, the waste is transported by special transport vehicles to its storage site for treatment in the medical incinerator inside the health institution.

There is a worker who specializes in burning medical waste, where he operates the incinerator and prepares it to burn waste according to the design capacity of the incinerator. The operating times are always within specific periods for this purpose. Still, the worker fails to comply with the operational specifications of the incinerator due to the lack of sufficient experience. The combustion degree required for the incinerator is not reached, which may sometimes get more than 850°C to ensure complete combustion and non-pollution of the environment with gases such as dioxin and furans.



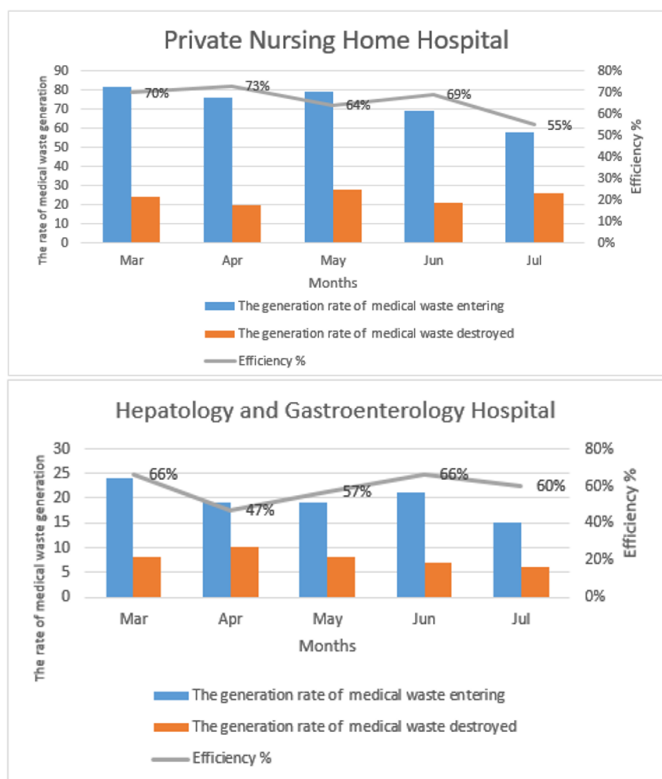


Figure 2. Efficiency of the medical waste incinerator in hospitals

Table 4. Minimum and maximum efficiency for incineration

Name of the Hospital	Minimum Efficiency (%)	Maximum Efficiency (%)
Baghdad Teaching Hospital	55	73
Specialized Surgery Hospital	37	55
Private Nursing Home Hospital	41	67
Children's Protection Hospital	55	73
Hepatology and Gastroenterology Hospital	47	66

Through Figure 2 and Table 4 for evaluating the efficiency of the incinerator's work, we find that the incinerator is inefficient in treatment and that the highest efficiency rate in waste removal was 73%, and the lowest rate was 37%. This is due to several reasons, including the age of the incinerator, the type of fuel used, and the lack of commitment to the operating hours of the incinerator to reach the required degree of combustion, which is reflected negatively in the treatment [12].

3.2 Bottom medical wastes ash analysis

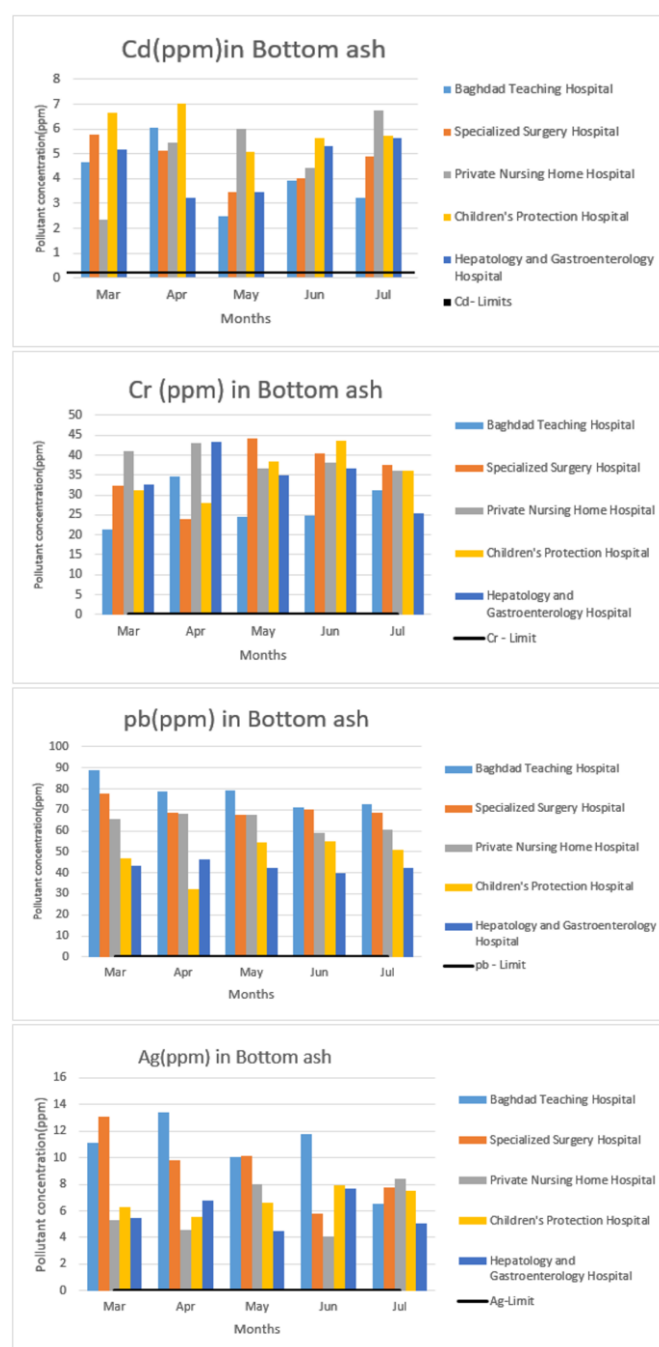
As mentioned above, the primary treatment of medical wastes is incineration because it reduces the volume of waste by about 95% and its weight by about 70%, and it is also the standard approach to waste disposal. Bottom ash, a combustion residue, makes up about 25-30% of the initial weight of the waste. This must be examined to see the efficiency of the incinerator treatment in getting rid of the heavy metals present in the waste before the final disposal of the ash in the landfill site.

The incineration of medical waste in existing incinerators produces two types of ash: bottom ash and fly ash. Bottom ash is ash recovered from the bottom of the medical waste incineration chamber after cooling it through its funnel. The second type, fly ash, refers to the incineration of residues collected by the waste incineration system's bag filter.

After laboratory tests of the bottom ash samples to determine the heavy metal concentrations of the incineration ash, the chemical analysis results were compared with international standards, as shown in Table 5 and Figure 3.

Table 5. Allowable limits for the concentrations of heavy elements in the ashes (US-EPA)

Metals	Limits Level (ppm)
Cadmium (Cd)	0.005
Chrome (Cr)	0.1
Lead (Pb)	0.015
Silver (Ag)	0.001
Arsenic (As)	0.001



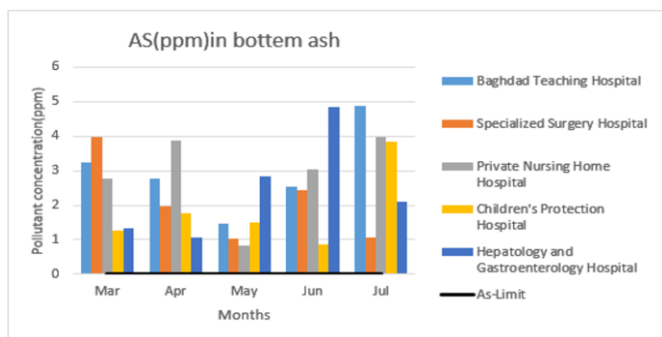


Figure 3. The concentration of heavy metals (Cd, Cr, Pb, Ag, As) in the bottom ash of incinerators

The above results note the high concentrations of heavy metals compared with the determinants. This is due to non-compliance with waste insulation, which leads to the burning of plastic waste, laboratory materials, and others. In addition, there is a lack of commitment to the time and heat required to operate the incinerator to get rid of those pollutants [13].

The analysis of heavy metal content in the medical waste incineration ash (Figure 3) gave the following results:

The Cd concentration is the lowest among the examined heavy metals in the medical waste incineration ash. Cd is a highly unstable metal that sublimates into the atmosphere during the incineration process, leading to a decrease in its concentration in the bottom ash [14]. While the Cr concentrations ranged from 44.19 to 21.31 ppm in the medical waste incineration ash. The high chromium concentrations are attributed to the presence of plastics, coatings, textiles, and other chromium-containing materials in the burned hospital waste [15]. In addition, the Pb concentrations ranged from 7.01 to 2.33 ppm in the current study and from 21.6 to 5 ppm in a study [16]. The lower lead concentrations in the current study may be due to the type of pollutants burned and the higher incineration temperature, which can result in the lead compounds being dissolved and absorbed into the bottom ash surface area [17].

On the other hand, the Ag concentrations ranged from 13.38 to 4.08 ppm, which is higher than the acceptable limit of 0.001 ppm. The presence of silver in the medical waste ash is attributed to its use in surgical equipment, medical instruments, and some pharmaceutical preparations [18]. Finally, the As concentrations ranged from 4.88 to 0.85 ppm, exceeding the permissible limit of 0.001 ppm. Arsenic is present in medical waste due to its use as an antifungal and antibacterial agent, as well as in insecticides and disinfectants. Exposure to arsenic can cause acute or chronic poisoning and serious health damage [19].

All heavy metal samples whose ash was examined in this research were above the permissible limits set by the standards of the United States Environmental Protection Agency. This gives an indication of the inefficiency of the incinerator treatment and therefore ash needs to be processed before safe disposal.

In Iraq, all health institutions dispose of ash at landfill sites. At times, the ash is either freely dumped in open areas or nearby pits, leading to soil contamination. This, in turn, allows pollutants to seep into the groundwater. Additionally, ash particles can become airborne, mixing with dust from the discharge site and posing inhalation risks. Over time, these pollutants may bioaccumulate in the flora and fauna surrounding the disposal areas. The recycling of ash and

contaminated soil containing heavy metals can have direct health impacts on workers, visitors to incinerator sites, individuals who burn waste at landfills, and those who engage in improper waste disposal.

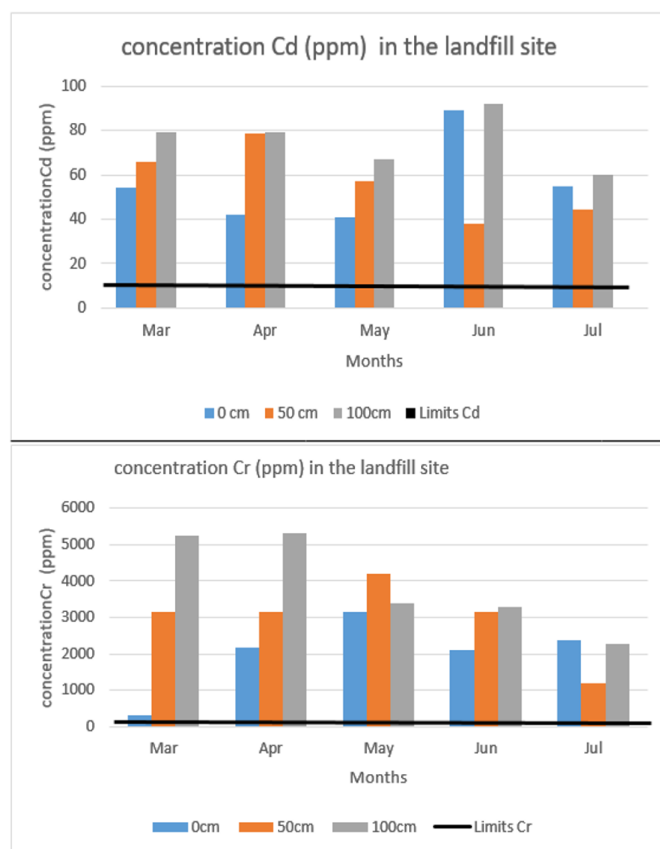
From the above, there is a health, environment, and financial need to enhance management on medical waste in order to minimize harm resulting from the waste and to avert more harm to the environment or human beings for these elements. It is also suggested that those decision makers of healthcare institutions ought to be motivated to embrace the necessity of training the waste managers and the workers on safe handling and using the low pollution technologies like the environmentally friendly incinerators as well as sponsoring the plans and strategies aimed at proper waste disposal like the bottom ash under the local and international recommended laws and regulations.

3.3 Determination of contaminant in soil landfill

Table 6. Soil standards of the sedimentary plain region in (Iraq and Holland standards) and (US- EPA) standards

Element	Concentration (ppm)	
	Iraq Standers	(US-EPA)
Copper (Cu)	1-85	*NA
Lead(Pb)	1-64	5.0
Zinc(Zn)	20-117	*NA
Vanadium (V)	4-380	*NA
Chromium (Cr)	4-2000	5.0
Nickel (Ni)	1-870	*NA
Netherlands Standards		
Beryllium (Be)	30	*NA
Cadmium (Cd)	12	1.0
Mercury (Hg)	380	0.2
Silver (Ag)	15	5.0
Arsenic (As)	55	5.0

Note: *NA: Not available.



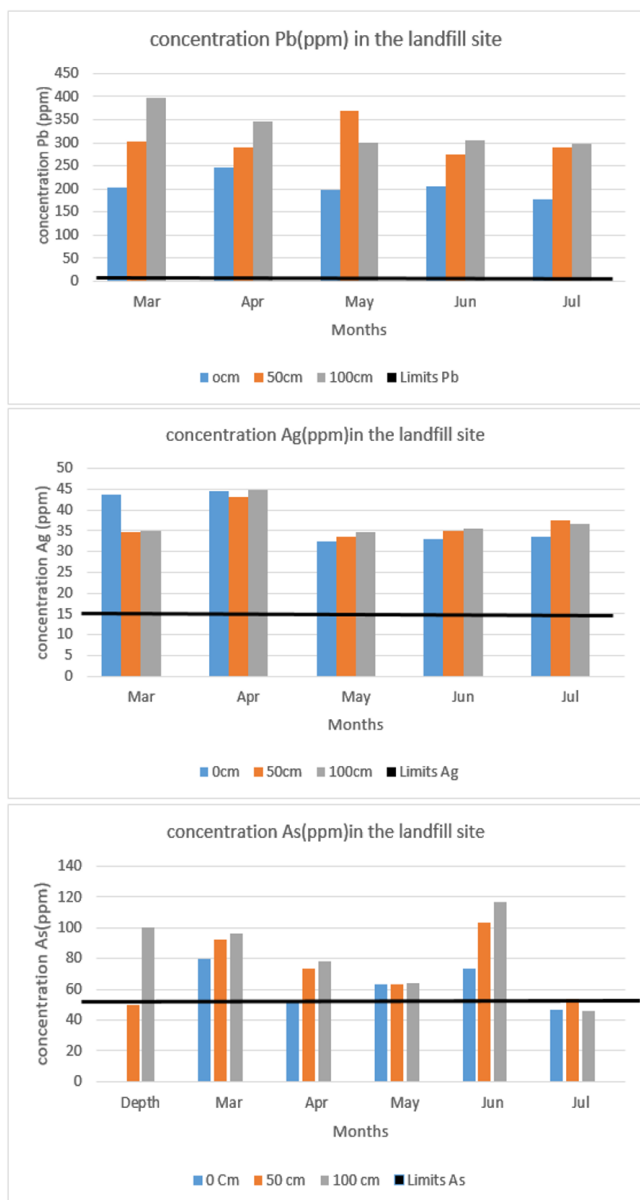


Figure 4. The concentration of (Cd, Cr, Pb, Ag, As) in the landfill site at different depths

Landfilling is a technique of wastes disposal whereby wastes are disposed on the surface of the land after perhaps having undergone some slight processing. Due to the negative impacts that may arise from the disposal of wastes, there are set guidelines that govern the placement of landfills and their running [20].

However, pollution through wastes is evident where there are no proper landfills since wastes are dumped anyhow and, in the process, affecting the environment in a big way. This is the case in Iraq where unabated dumping is rampant [21, 22].

The study compared the concentrations of heavy metals (Pb, Cd, Ag, As, Cr) in the soil samples collected from the landfill site with the environmental standards adopted in Iraq and also used the standards from the Netherlands, as the soil composition was similar to that of Iraq as shown in Table 6 and Figure 4.

The comparison of the results of the determination of heavy metals (Pb, Cd, Ag, As, Cr) with the environmental standards adopted made it possible to state that the concentrations of these metals in the soil samples collected from the landfill site were significantly higher. For other mineral elements, the researchers relied on the Dutch standards since the composting

of the soil was similar with Iraq. It is for this reason that high concentrations of heavy metals are found in the groundwater since Iraqi has no proper hazardous waste landfill and all types of hazardous waste including ash is dumped at the municipal landfill site. This is made worse by the fact that the majority of the municipal dumps in Iraq failed to meet basic requirements, including having a layer of material between the waste disposed and the ground.

Some of the contributors to the pollution of the surrounding environment include the exhaustion of the landfill's life and the cases of unabated burning within the site. This is a big issue, especially in urban centres where environmentally sensitive waste disposal is on the rise due to factors such as: escalating cost, limited space, stringent standards on environmental disposal, and social unacceptance of new dumpsites [23]. In the case of Iraq, the increase in population mobility and urban enlargement predetermined the fact that many residential areas are located adjacent to the landfill sites and this factor entails great threat to human health and environment if appropriate site characteristics and strict environmental protection measures for hazardous wastes are not provided [24].

4. CONCLUSION AND RECOMMENDATIONS

This study showed that existing knowledge on the handling/ how to dispose of, and manage medical waste in Baghdad is inadequate. The hazardous concentrations of heavy metals defined in the samples of bottom ash were 8-12 times of the permissible norms, which showed critical problems in the functioning of incinerators. Cd content varied in the range of 4.88 to 0.85 ppm, beyond which is a permissible limit of 0.001 ppm, and Cr concentrations were the lowest concentration of heavy metals in the waste ashes, which was recorded as 44.19 to 21. The key contributing factors in this pollution includes: Pre-conditioning and segregation not well done-burning of wrong items such as plastics, laboratory wastes, and other non-clinical waste, which release toxic substances during the incineration process. Lack of control in operations, the incinerators are not being run at the right time and temperature, that is required to eliminate as well as capture these heavy metals and other chemicals. The poor, improper and inefficient means of burning and the disposal of the final residues, which are ash, have highly polluted the soil and the underground water around the Landfill sites. The Pb, As, Cr, Cd, Ag concentration in the soil were Exceeding the permissible limits. These present a major threat to the environment and the public health, which requires adequate attention to be paid, such as a green hospital by enhancing an efficient framework of handling the medical wastes. This should include: Compliance to the waste disposal best practices as follows: Compliance to segregation at the source level, Modernization of incineration systems to the best in the world standards such as high-temperature incinerators or flue gas treatment devices, using Autoclave shredding instead of incineration, Proper disposal of the ash produced by incineration that entails removal of heavy metals and other dangerous materials, Constant check on pollution levels around the site of disposal. The aforementioned changes are essential to address the effects of the existing poor medical waste management on the environment and the public's health in Baghdad. If this does not occur, the accustoming of the environment's condition and the health impacts on the residents will perpetuate.

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