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Original Research Article

Impact of hospital waste on soil and water heavy metal levels in surrounding areas

Rashi *, Yogesh Kumar, Dr. Sumer Singh

Department of Chemistry, Singhania University, Pacheri Bari, Rajasthan, India
*Corresponding author, E-mail: rashiy2316@gmail.com

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ABSTRACT
Healthcare waste contains infectious, chemical and metallic residues that require careful treatment before disposal. Incineration reduces waste volume and destroys pathogens, yet poor control of ash, emissions and leachate can transfer persistent pollutants into surrounding soil and water. This study examines heavy metal contamination around four 200-600 bed hospitals in Haryana, India, using field observations, hospital waste-type surveys, soil sampling near incinerators and dumpsites, and water sampling from adjacent sources. Soil and water samples were analysed for selected heavy metals using atomic absorption spectrophotometry, and results were interpreted against recognised environmental safety limits. The findings show that incinerator-adjacent soils contained detectable concentrations of Pb, Mn, Co, Ni and Cr, with Pb ranging from 5.57 to 7.70 mg/L. Adjacent dumpsite soils were acidic, with pH values between 4.34 and 4.80, which may increase the mobility of some metals. Water quality results were more concerning: Pb ranged from 29.38 to 48.24 microgram/L against the WHO permissible level of 10 microgram/L; Cd ranged from 3.06 to 7.49 microgram/L against 3 microgram/L; Cr ranged from 61.56 to 84.92 microgram/L against 50 microgram/L; Hg ranged from 1.62 to 3.45 microgram/L against 1 microgram/L; and As exceeded the 10 microgram/L level at all four sites. The evidence indicates that hospital incineration can remain an environmental risk when ash disposal, segregation, leachate prevention and routine monitoring are weak. The paper recommends controlled ash handling, periodic heavy metal surveillance, strengthened segregation, staff training, and transparent environmental reporting for healthcare facilities.

1. Introduction

Healthcare waste is produced during diagnosis, treatment, immunisation, laboratory testing and research activities. Although most healthcare waste is comparable to general waste, a smaller but highly important fraction contains infectious agents, sharps, pharmaceuticals, chemical residues, heavy metals and radioactive materials. The safe management of this waste is therefore both a public health and environmental governance issue. The World Health Organization [1] emphasises segregation at source, safe storage, appropriate treatment and controlled final disposal because poor handling can expose healthcare workers, waste handlers, patients and surrounding communities to avoidable hazards.

Incineration is widely used for infectious healthcare waste because it destroys pathogens and reduces the volume and reactivity of waste. However, incineration does not remove metallic constituents from the waste stream. Instead, metals may become concentrated in bottom ash and fly ash, while incomplete combustion and poor emission controls can release particulate matter and toxic compounds into the surrounding environment [2], [3]. Incinerator ash may contain lead, cadmium, chromium, mercury, zinc and other potentially toxic elements, especially when waste segregation is weak and items such as thermometers, pressure-monitoring devices, batteries, plastics and laboratory chemicals enter the burn stream [4], [5].

In developing and rapidly urbanising settings, the problem is intensified by increasing healthcare demand, limited waste infrastructure, irregular environmental monitoring and continued reliance on small-scale treatment units. Where ash is dumped openly or stored near healthcare facilities, rainwater runoff and leachate can carry metals into soil and groundwater. Such contamination matters because heavy metals persist, may bioaccumulate, and can affect the respiratory, renal, neurological, reproductive and developmental systems of exposed populations [6], [7], [8]. The risk is especially serious when hospitals are located close to residential areas, agricultural land or local water sources.

Previous research has discussed biomedical waste management practices, disposal technologies and occupational risks, yet there remains a need for site-based evidence that links hospital incineration with measurable soil and water contamination. Many studies report treatment practices or general awareness levels, but fewer combine waste-type profiling, soil chemistry, water quality and heavy metal comparison against permissible limits in the same healthcare setting. A recent empirical assessment of hospital incinerator environments in Haryana reported elevated levels of selected metals in soil and water near healthcare waste treatment and disposal sites [9]. Building on this evidence, the present paper provides a clearer, more structured and policy-oriented analysis of how hospital incineration can contribute to heavy metal contamination in surrounding environmental media.

The objectives of the study are: (i) to identify the types of healthcare waste generated in selected hospitals; (ii) to assess physicochemical characteristics of soil around incinerators and dumpsites; (iii) to evaluate selected heavy metals in soil and water samples; (iv) to compare water metal concentrations with permissible limits; and (v) to propose practical measures for reducing environmental and health risks associated with hospital waste incineration.

2. Literature review

2.1 Healthcare waste and incineration

Healthcare waste management requires a treatment chain that begins with segregation and ends with safe disposal. If infectious, chemical, pharmaceutical and recyclable wastes are mixed, treatment becomes more expensive and the hazard load entering incinerators increases. Rajan et al. [10] and Sahiledengle [11] show that segregation practices remain uneven across healthcare institutions, particularly where training, infrastructure and supervision are limited. Recent reviews also note that many healthcare facilities still struggle to align daily practice with biomedical waste rules, even where formal regulations exist [12], [13], [14].

Incineration remains important for specific infectious waste streams, but it should not be treated as a universal solution. Alavi and Khodadadi [15] argue that alternative methods such as autoclaving, chemical treatment and microwave-based disinfection can reduce environmental burdens when the waste stream does not require combustion. Mazzei and Specchia [16] similarly indicate that treatment choice should be guided by waste composition, technology availability, energy use, emission control and final residue management. The key weakness of incineration is not only the stack emission, but also the ash residue that can contain concentrated metals and persistent organic pollutants.

2.2 Heavy metals in soil and water around waste sites

Heavy metals released from waste disposal sites can remain in soil for long periods. Their movement depends on soil pH, organic matter, clay content, redox conditions and cation exchange capacity [17], [18]. Acidic soils can increase the mobility of certain metals, making leaching into groundwater more likely. Nemati et al. [19] caution that total metal concentration alone may not fully represent risk because metal speciation affects mobility and bioavailability. This makes both concentration measurement and environmental context important.

Studies on medical waste incinerator ash have reported metals such as Pb, Cd, Cr, Cu, Zn and Hg in bottom ash and surrounding soils. Gidarakos et al. [4] found that hospital waste incineration residues could present hazardous characteristics, while Zhao et al. [5] reported typical pollutants in bottom ash from medical waste incinerators. Auta and Morenikeji [20] also observed elevated heavy metal concentrations around a hospital incinerator and a dumpsite in Nigeria. Such findings suggest that hospital waste treatment facilities need monitoring beyond the hospital boundary.

2.4 Synthesis of previous studies and research gap

Table 1: Synthesis of selected studies on healthcare waste incineration and environmental risk.

Study	**Focus**	**Method or setting**	**Key insight**	**Remaining gap**
Batterman [2]	Small-scale healthcare waste incinerators	WHO assessment	Incinerators can reduce infectious risk but may create emission and residue problems if poorly controlled.	Limited facility-level contamination data.
Gidarakos et al. [4]	Hospital waste incinerator bottom ash	Hazard characterisation	Bottom ash can contain hazardous constituents requiring controlled disposal.	Less emphasis on nearby water pathways.
Zhao et al. [5]	Medical waste incinerator ash	Pollutant characterisation	Heavy metals are common in bottom ash from medical waste incineration.	Site-specific health governance is not fully addressed.
Alavi and Khodadadi [15]	Incineration and alternatives	Waste management review	Alternative treatments can reduce dependence on combustion for suitable waste streams.	Empirical comparison across local hospitals remains limited.
Bano et al. [6]	Medical waste consequences and strategies	Review study	Environmental and health consequences require integrated management strategies.	More field-based heavy metal evidence is needed.
Impact of Hospital Waste Incineration [9]	Hospital incineration and environmental contamination in Haryana	Four-hospital assessment with soil and water testing	Pb, Cd, Cr, Hg and other metals were detected at levels of concern around healthcare waste sites.	Findings require clearer framing, statistical interpretation and policy translation.

2.3 Environmental health and governance issues

Environmental contamination from healthcare waste can affect health directly through exposure to polluted soil, ash, dust and water, and indirectly through crops, livestock and aquatic systems. Harhay et al. [21] describe healthcare waste as a neglected public health issue worldwide, particularly in contexts where safe disposal systems are underdeveloped. Bano et al. [6] further argue that medical waste mismanagement is a present-day environmental issue because it combines infection risk, chemical toxicity and poor institutional compliance.

The governance dimension is central. Effective healthcare waste management requires clear institutional responsibility, reliable waste records, trained staff, colour-coded segregation, safe internal transport, certified treatment operators, environmental monitoring and community risk communication. Without these controls, even technically acceptable treatment systems can become pollution sources. In this sense, the environmental safety of incineration depends not only on the machine but also on the surrounding governance system.

3. Theoretical and conceptual framework

The paper is grounded in a source-pathway-receptor risk framework. In this framework, the source is the hospital waste stream and incinerator ash; the pathways are emission deposition, ash dispersal, leachate, runoff and groundwater movement; and the receptors are healthcare workers, waste handlers, residents, soil organisms, crops, aquatic species and groundwater users. This framework is useful because it connects waste management decisions with measurable environmental outcomes and exposed populations.

The study also draws on the waste management hierarchy, which prioritises waste prevention, minimisation, segregation, reuse where safe, treatment and controlled disposal. For healthcare waste, the hierarchy does not remove the need for incineration in all cases, but it requires that only appropriate waste fractions enter the incinerator. Metals, batteries, pressurised containers, pharmaceuticals and chemical residues should be excluded where possible because they increase toxic residues. The conceptual model in Figure 1 shows how weak segregation and poorly managed incineration can create soil and water contamination pathways.

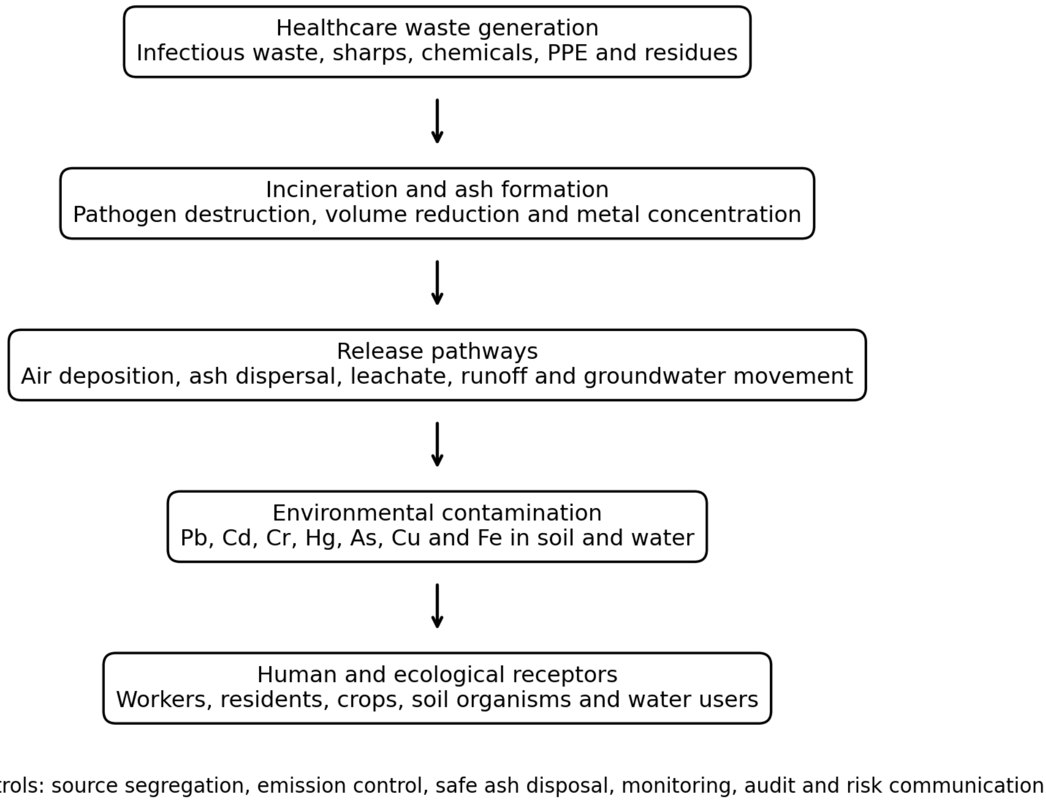

Figure 1: Conceptual framework linking healthcare waste incineration with environmental exposure pathways.

4. Materials and methods

4.1 Study design and site selection

A cross-sectional environmental assessment design was used. Four state hospitals located in Haryana, India, were selected. Each hospital had an estimated bed strength of 200-600 and was located near residential areas. For confidentiality and comparability, the sites are identified as Hospital A, Hospital B, Hospital C and Hospital D. The design focused on incinerator-adjacent soil, dumpsite-adjacent soil and water sources located near the selected healthcare facilities.

4.2 Waste-type survey

Hospital staff were surveyed regarding the types of waste generated and the broad disposal practices followed at the facilities. The survey covered biological materials, sharps, fluids, personal protective items, chemical waste and other healthcare residues. The purpose of the survey was not to measure waste mass, but to establish whether high-risk waste categories were present at each hospital.

4.3 Soil sampling and preparation

Soil samples were collected from areas close to hospital incinerators and from adjacent dumpsite locations between May 2025 and January 2026. For each sampling point, composite samples were prepared from randomly selected subsamples. Approximately 30 g of soil was stored in labelled zip-lock bags for laboratory testing. Sampling tools were washed, rinsed with distilled water and dried between sites to reduce cross-contamination.

In the laboratory, 5 g of each soil sample was digested using perchloric acid, nitric acid and sulphuric acid. Blanks were prepared to check reagent contamination. The analysis focused on selected heavy metals, including Cd, Cr, Ag, Hg, Pb and Zn in the wider design, while reported tabulated soil values included Pb, Mn, Cd, Co, Ni and Cr.

4.4 Water sampling and analysis

Water samples were collected from sources near the four hospitals. Three sets of water samples were taken at each location. On arrival at the laboratory, 1 mL of concentrated nitric acid was added to each 100 mL of sample, followed by filtration. A 10 mL aliquot was then used for atomic absorption spectrophotometry. Standard solutions were prepared for calibration across the relevant concentration ranges. Initial pH was measured using an Inolab pH meter.

4.5 Instrumentation and quality assurance

Heavy metals were measured using atomic absorption spectrophotometry. Cd, Cr, Ag, Pb and Zn were analysed in flame mode, while Hg was analysed using cold vapour mode. The study included reagent blanks and calibration standards. For a stronger reproducibility protocol, routine use of certified reference material, duplicate samples, matrix spikes, calibration verification and method detection limits is recommended in future monitoring programmes.

4.6 Data analysis

Results were reported as mean ± standard deviation where replicate values were available. One-way analysis of variance was identified as the main inferential test for comparing sites. In addition, this paper reports descriptive ranges and exceedance ratios, calculated as observed concentration divided by the stated permissible level. Exceedance ratios greater than 1 indicate that the observed concentration is above the relevant limit. Because raw replicate-level data were not available for all water measurements, interpretation focuses on environmental significance.

5. Results

5.1 Types of waste generated by hospitals

All four hospitals generated urine, faeces, blood, gloves, syringes, specimens, injection bottles, used cotton, gauze and swabs. More specialised or less frequent waste types, such as ascitic fluid, cerebrospinal fluid, expired fluids, chemicals and body parts, were reported mainly in Hospitals C and D. This pattern indicates that all hospitals produced infectious and sharp waste requiring strict segregation, while some facilities also generated chemical and anatomical waste requiring additional controls.

Table 2: Waste types generated by the four hospitals.

Waste type	A	B	C	D
Urine	Y	Y	Y	Y
Faeces	Y	Y	Y	Y
Blood	Y	Y	Y	Y
Sputum	Y	N	Y	N
Ascitic fluid	N	N	Y	N
CSF	N	N	N	Y
Water used	N	N	Y	Y
Skin	Y	N	Y	Y
Pus	N	Y	Y	Y
Expired fluids	N	N	Y	Y
Chemicals	N	N	Y	Y
Gloves	Y	Y	Y	Y
Body parts	N	N	Y	Y
Syringes	Y	Y	Y	Y
Specimens	Y	Y	Y	Y
Injection bottles	Y	Y	Y	Y
Used cotton	Y	Y	Y	Y
Gauze	Y	Y	Y	Y
Swabs	Y	Y	Y	Y

Note. Y = present; N = absent.

5.2 Physicochemical characteristics of incinerator-adjacent soil

The field observations showed black colour and foul odour in soil around the incinerator locations. Soil temperatures ranged from 26±6.01°C to 28±6.21°C. The pH values were consistently close to 6.28, suggesting mildly acidic to near-neutral conditions in the incinerator-adjacent soil samples.

5.3 Heavy metals in incinerator-adjacent soil

Pb was the dominant reported metal in the incinerator-adjacent soil samples, with concentrations between 5.57±0.04 and 7.70±0.03 mg/L. Co ranged from 0.42±0.03 to 0.64±0.01 mg/L, Cr ranged from 0.15±0.00 to 0.51±0.03 mg/L, Ni ranged from 0.03±0.00 to 0.11±0.03 mg/L, and Mn ranged from 0.05±0.01 to 0.30±0.02 mg/L. Cd was not detected in the reported soil table. The higher Pb values indicate a need for careful control of ash residue and further testing of lead-bearing waste items entering the incineration process.

Table 3: Physicochemical characteristics of soil near incinerator sites.

Parameter	A	B	C	D
Colour	Black	Black	Black	Black
Odour	Foul	Foul	Foul	Foul
Temperature (°C)	27±5.89	28±6.19	26±6.01	28±6.21
pH	6.28±0.02	6.28±0.01	6.28±0.005	6.28±0.003

Table 4: Heavy metal concentrations in incinerator-adjacent soil samples.

Parameter	A	B	C	D
Pb (mg/L)	5.57±0.04	7.70±0.03	6.52±0.02	5.57±0.04
Mn (mg/L)	0.06±0.01	0.05±0.01	0.30±0.02	0.07±0.00
Cd (mg/L)	ND	ND	ND	ND
Co (mg/L)	0.51±0.02	0.64±0.01	0.42±0.03	0.58±0.02
Ni (mg/L)	0.03±0.00	0.11±0.03	0.08±0.00	0.09±0.00
Cr (mg/L)	0.48±0.02	0.51±0.03	0.15±0.00	0.42±0.01

Note. ND = not detected in the reported table.

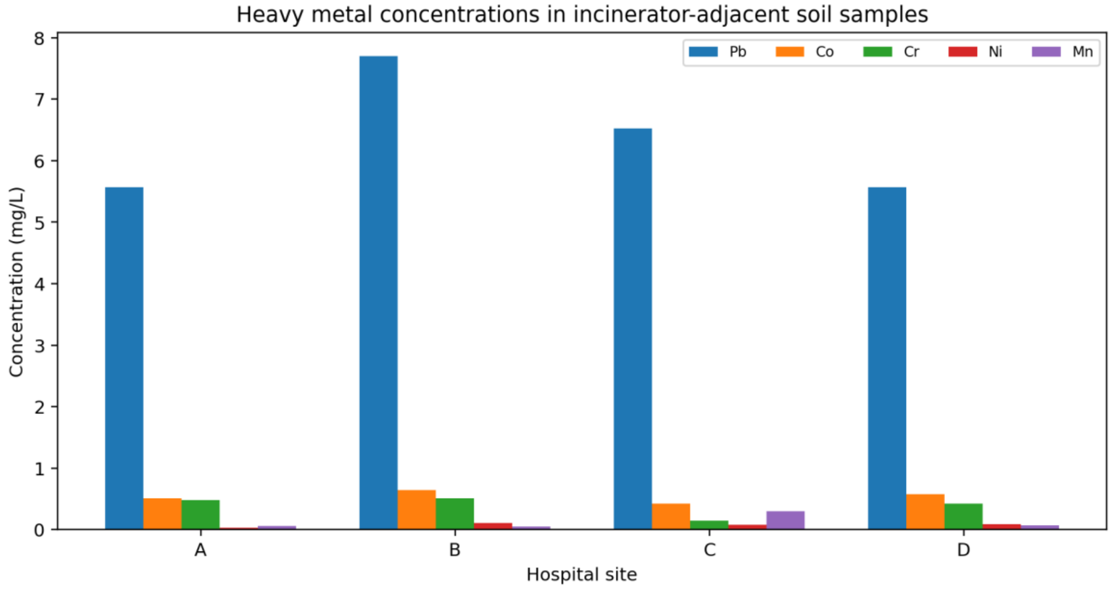

Figure 2: Heavy metal concentrations in incinerator-adjacent soil samples.

5.4 Heavy metals in adjacent dumpsite soil

Dumpsite-adjacent soils showed brown colour with normal odour and were more acidic than the incinerator-adjacent soil samples. The pH values ranged from 4.34±0.002 at Site C to 4.80±0.01 at Site A. Such acidic conditions are environmentally important because they can increase the mobility of some metals and raise the possibility of leaching. Pb remained measurable at all sites, ranging from 3.26±0.02 to 6.52±0.02 mg/L, while Mn was markedly higher at Site C than at other sites.

Table 5: Physicochemical and heavy metal characteristics of dumpsite-adjacent soil.

Parameter	A	B	C	D
Colour	Brown	Brown	Brown	Brown
Odour	Normal	Normal	Normal	Normal
Temperature (°C)	27±5.89	26±6.19	27±6.01	26±6.21
pH	4.80±0.01	4.68±0.01	4.34±0.002	4.73±0.001
Pb (mg/L)	3.26±0.02	3.83±0.01	6.52±0.02	5.57±0.04
Mn (mg/L)	0.05±0.001	0.06±0.002	2.28±0.003	0.04±0.001
Cd (mg/L)	ND	ND	ND	ND
Co (mg/L)	0.09±0.01	0.46±0.002	0.53±0.01	0.31±0.003
Ni (mg/L)	0.04±0.00	0.08±0.02	0.05±0.003	0.07±0.002
Cr (mg/L)	0.36±0.01	0.28±0.01	0.31±0.002	0.38±0.01

5.5 Heavy metals in water samples

Water samples showed clear exceedances for several metals when compared with the stated WHO permissible levels. Pb exceeded the limit at all four sites, with the highest value at Site B (48.24 microgram/L), equivalent to 4.82 times the permissible level. Cd exceeded the limit at all sites, with Site D recording 7.49 microgram/L, or 2.50 times the permissible level. Cr exceeded the limit at all sites, while Hg and As also exceeded their respective limits in every sample. Cu was above the permissible level at all sites. Fe exceeded the stated limit at Sites B, C and D, whereas Ni remained below the stated permissible level at all sites.

Table 6: Heavy metal concentrations in water samples and comparison with permissible levels.

Parameter	A	B	C	D	Permissible level	Highest exceedance
Pb (µg/L)	45.62	48.24	34.84	29.38	10	4.82×
Cd (µg/L)	3.06	5.48	6.57	7.49	3	2.50×
Cu (µg/L)	62.17	74.03	69.35	81.45	50	1.63×
Ni (µg/L)	26.28	32.65	41.32	34.69	200	Below limit
Cr (µg/L)	61.56	78.49	75.62	84.92	50	1.70×
Hg (µg/L)	2.69	3.45	1.62	2.32	1	3.45×
As (µg/L)	10.63	11.23	12.45	13.68	10	1.37×
Fe (µg/L)	937	1121	1209	1087	1000	1.21×

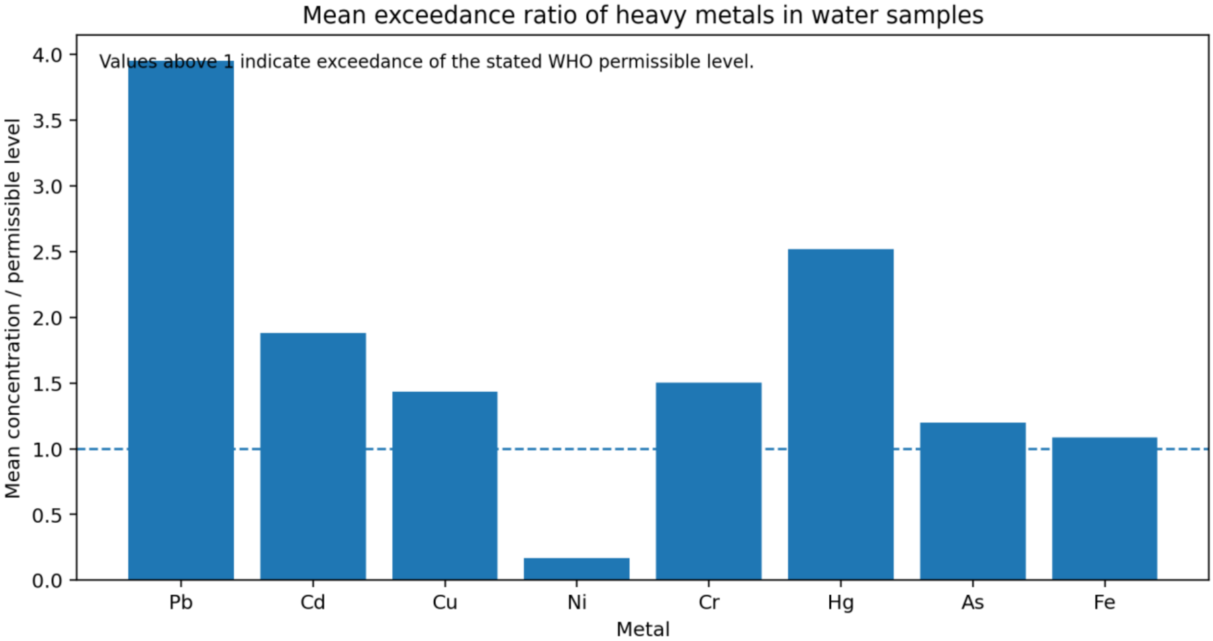

Figure 3: Mean exceedance ratio of heavy metals in water samples.

6. Discussion

6.1 Interpretation of soil contamination patterns

The soil results suggest that incineration and associated ash handling can act as a local source of heavy metals. The presence of Pb, Co, Ni and Cr in incinerator-adjacent soil is consistent with literature showing that metallic constituents are not destroyed by combustion and may become concentrated in ash residues [4], [5]. The higher Pb values are particularly important because lead exposure is associated with neurological and developmental harm, and because lead-bearing materials can enter healthcare waste streams through equipment, plastics, paints, batteries and electronic components.

The dumpsite-adjacent soils showed lower pH values than the incinerator-adjacent soils. Acidic conditions can increase metal solubility and mobility, depending on soil chemistry and metal speciation. Wuana and Okieimen [17] note that soil pH, organic matter and mineral composition shape metal retention and transport. The acidic dumpsite environment therefore requires attention even when some metal values appear moderate, because mobility and exposure risk may increase under unfavourable chemical conditions.

6.2 Water contamination and public health relevance

Water contamination is the most immediate concern in the present evidence. Pb, Cd, Cu, Cr, Hg and As exceeded the stated permissible levels at all four sites, while Fe exceeded the limit at three sites. These findings point towards possible leaching, runoff or shared contamination sources around healthcare waste treatment and disposal areas. The values do not prove a single pathway on their own, but they strongly justify more detailed hydrogeological investigation and routine testing of nearby water sources.

The health relevance of the water findings is clear. Pb and Hg are neurotoxic; Cd can affect the kidney and skeletal system; Cr may have carcinogenic implications depending on valence state; and As exposure is linked with skin, cardiovascular and cancer risks. The presence of multiple metals above permissible levels is more concerning than isolated exceedance because communities may face cumulative exposure through drinking water, food chains and contact with contaminated soil. The findings therefore support the argument that healthcare waste management should be integrated into local water safety planning rather than treated only as an internal hospital sanitation matter.

6.3 Implications for hospital waste management

The waste-type survey indicates that all hospitals generated infectious waste and sharps, while some generated chemical, fluid and anatomical waste. This has direct implications for segregation. If chemical or metal-bearing items enter incinerators with infectious waste, ash toxicity increases. Facilities should therefore treat segregation as an environmental control measure, not merely as an administrative requirement. Colour-coded bins, point-of-generation sorting, staff training, supervision and documentation are essential.

The study also highlights the need for controlled ash management. Bottom ash should not be disposed of in open pits near healthcare facilities. It should be cooled, stored in covered and labelled containers, tested periodically for hazardous constituents, and transported to authorised facilities. Where ash displays hazardous characteristics, it should be managed under stricter containment and landfill protocols. Hospitals should also maintain records of waste volume, incineration conditions, ash transfer and environmental monitoring results.

6.4 Policy and regulatory implications

At policy level, the findings call for routine environmental surveillance around hospital waste incinerators, particularly in hospitals located close to residential communities. Regulators should require periodic testing of soil, ash, stack emissions and nearby water sources. Audit systems should move beyond checking the existence of an incinerator and should evaluate whether the full waste management chain is functioning safely. Public disclosure of monitoring results can also improve accountability and community confidence.

Healthcare institutions should also consider technology selection. Incineration should be reserved for waste streams for which combustion is appropriate. Non-incineration methods such as autoclaving or chemical disinfection may be preferable for many infectious waste categories when properly implemented [15], [16]. Reducing the volume of waste entering incinerators can reduce ash generation and potential environmental burden.

7. Recommendations

- Strengthen segregation at source so that chemicals, batteries, mercury-containing items, pharmaceuticals and recyclable materials do not enter the infectious waste incinerator stream.
- Introduce routine heavy metal monitoring of incinerator ash, nearby soil and nearby water sources at fixed intervals.
- Store bottom ash in covered, labelled and leak-proof containers before transport to authorised disposal facilities.
- Use non-incineration treatment methods for suitable waste fractions to reduce combustion residues and emissions.
- Train healthcare workers, sanitation workers and waste handlers on environmental risks, segregation rules and personal protective equipment.
- Create facility-level waste records covering waste categories, treatment method, ash quantity, disposal location and monitoring results.
- Conduct community risk communication for hospitals located close to residential areas or shared water sources.
- Develop independent audits that include environmental sampling rather than relying only on paperwork compliance.

8. Limitations and future research

The study provides useful site-based evidence, but it has limitations. The number of hospitals was limited to four, and results may not represent all healthcare facilities in Haryana or India. Some water results were reported without standard deviations, which limits detailed inferential testing and confidence interval estimation. The study also did not include seasonal comparison, groundwater flow mapping, metal speciation or human biomonitoring. Future research should include larger multi-season sampling, replicate-level data reporting, comparison with control sites, source apportionment, ash leachability tests and health risk assessment using exposure models.

9. Conclusion

Hospital waste incineration can reduce infectious risk, but it can also create environmental risk when segregation, combustion control and ash disposal are weak. Evidence from four hospitals in Haryana shows that incinerator-adjacent and dumpsite-adjacent soils contain measurable heavy metals, while nearby water samples exceed permissible levels for several metals, including Pb, Cd, Cr, Hg and As. The results indicate that healthcare waste management should be treated as a continuous environmental governance process rather than a narrow disposal activity. Hospitals require stronger segregation, safer ash management, regular monitoring and transparent reporting. These measures are necessary to protect soil, water, workers and neighbouring communities from long-term contamination.

Authors' contributions

All authors contributed equally to the conception, design, experimental work, data analysis, interpretation of results, and preparation of the manuscript. All authors reviewed and approved the final version of the manuscript for publication.

Conflicts of interest

The author declares no conflict of interest.

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Data availability

No new data were created.

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