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Environmental Assessment of Heavy Metal Accumulation in Soil and Dust Surrounding Healthcare Facilities in Al-Qadisiyah, Iraq

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Abstract

Urban heavy metal contamination presents a critical challenge to environmental and public health, especially within healthcare environments that house vulnerable populations. This study evaluates the accumulation and health risks of lead (Pb), cadmium (Cd), mercury (Hg), zinc (Zn), copper (Cu), chromium (Cr), and nickel (Ni) in soil and surface dust at five major healthcare facilities in Al-Diwaniyah, Iraq. A total of 30 samples were collected from hospital gardens, windows, and waiting areas to represent both outdoor and indoor exposure. Analysis was performed using atomic absorption spectrophotometry following controlled acid digestion. Results indicated that heavy metal concentrations vary significantly across sites, with Pb levels peaking at Al-Diwaniya Hospital (44.20 mg/kg) and Ni frequently exceeding safety standards. Non-carcinogenic health risk assessments using USEPA models revealed that ingestion is the primary exposure pathway. While most metals posed minimal risk, mercury (Hg) at Al-Sadr II Hospital exceeded the safety threshold (HQ > 1), suggesting potential localized health concerns. These findings underscore the urgent need for improved medical waste management and continuous environmental monitoring within hospital settings.

Keywords: Heavy metals, Hospitals, Health risk

Introduction

Heavy metal contamination is a worldwide problem due to its unique features and long-term consequences on ecosystems and human health. Heavy metals including lead, cadmium, mercury, and chromium do not biodegrade, hence they remain in environmental matrices for a long time. They may also bioaccumulate and biomagnify up food chains. Their environmental impact is modest and expanding as they travel via the air, water, and soil. (Tchounwou, 2012) .

Rapid population growth, industrial activity, an expanding car population, and a range of service activities make heavy metal pollution increasingly widespread in cities. The interaction of these variables releases large amounts of metallic contaminants into the atmosphere. Soil and surface dust become environmental reservoirs for these pollutants. Urban dust and dirt are important environmental indicators of pollution levels because they collect contaminants from a broad range of sources, including industrial discharges, air pollutants, and human wastes. (Mohammad Ali, et al., 2021).

Heavy metals enter the body by direct ingestion, inhalation, and cutaneous absorption from polluted environments (He et al., 2021). These routes are typically undetected, exposing people to minuscule levels of heavy metals. This exposure may induce neurological illnesses, kidney and liver ailments, respiratory issues, and stunted growth in children, according to many studies. (Briffa & Blundell, 2020)

Hospitals and other healthcare institutions are potential heavy metal buildup sites. Despite providing healthcare, these facilities pollute the environment. Several internal sources may contribute to environmental heavy metals. Trash, laboratory chemicals, metallic medical equipment, and medical waste are improperly cremated or disposed of. Industrial emissions and heavy traffic near hospitals increase heavy metal concentrations in soil and dust. (Okoro, et al., 2025).

However, health risk assessment is essential for comprehending environmental pollution's effects. It makes it easy to link pollution levels to health risks. USEPA models are popular in this industry because of their excellent scientific foundation and capacity to assess hazards from ingestion, inhalation, and skin absorption. These methods simplify the calculation of the Hazard Quotient and Hazard Index to evaluate if contaminants provide a non-cancer health risk. (He, et al., 2021).

Environmental contamination estimates depend on soil and dust heavy metal content measurements, but they don't convey the entire picture about health risks. This illustrates the need of Health Risk Assessment (HRA). Health Risk Assessment (HRA) is a complicated scientific method that matches reported concentrations with potential health consequences by examining numerous exposure routes and predicting human body absorption. (Zheng et al., 2015).

The US Environmental Protection Agency's (EPA) Human Risk Assessment (HRA) models calculate a person's Average Daily Dose (ADD) from skin contact, inhalation, and eating. These channels are crucial in cities, where heavy metals may be easily taken into the body via polluted dust, which impacts children and other vulnerable populations. (Lai et al., 2024).

If the Hazard Quotient (HQ) is less than one, it is considered relatively safe to be exposed to; values more than one indicate the potential for harmful health effects. Exposure to multiple elements or pathways may have cumulative effects, which the Hazard Index (HI) attempts to assess. (Wang et al., 2023).

Because indoor air is fragile and patients, staff, and visitors are constantly exposed to it, these models are crucial in healthcare. In settings with poor ventilation or near pollution sources like factories or busy highways, heavy metals in interior dust may increase the risk of long-term exposure. (Rana, et al., 2024).

According to recent studies, the ingestion route is often the main cause of health concerns, particularly in children, because of behaviors like putting contaminated surfaces on their mouths and touching them. Air dilution and dispersion reduce the effect of inhalation, while dermal absorption has the least effect as metal transfer via the skin is ineffective. Thus, by merging environmental pollution data with health risk assessment models, we may better identify potential repercussions and devise effective ways to limit exposure and risk. Better medical waste management, ventilation, or hospital pollution reduction may accomplish this. This strategy helps policymakers implement research-based health and environmental policies to safeguard health and healthcare facilities.

Materials and Methods

Study Area

The study was conducted in Al-Diwaniyah, a strategic transportation and industrial hub in central-southern Iraq (31.73°N, 44.69°E) characterized by a hot, arid climate with significant seasonal temperature variations and an annual precipitation of 105.5 mm. As a growing center for industry—housing facilities such as tire and textile factories—the city faces potential environmental impacts from both industrial activities and dense urban services. This research specifically focuses on five key healthcare facilities: Diwaniya Teaching Hospital, Women and Children Teaching Hospital, Al-Daghara Health Center, Al-Sadr II Primary Healthcare Center, and Al-Sadr III Health Center, to evaluate the environmental conditions surrounding these vital medical institutions.

Sample Collection and analysis

For this study, 30 samples of soil and dust were collected on December 9, 2024, from five healthcare facilities. Dust was sampled from windows and waiting areas to capture airborne particles, while soil was taken from gardens at a depth of 3–5 cm to target the layer most exposed to human activity (Radhi, Shartooh, & Al-Heety, 2021; Al-Swadi, et al., 2022). Samples were secured in labeled polyethylene bags and transported for immediate analysis (Jaafar & Kadhum, 2023). Following air-drying and sieving (75µm), 0.5–1 g of each sample underwent acid digestion using a 2:4 ratio of HNO_3 and $HClO_4$, with temperatures gradually increasing to 140°C (Ismail, 1993). The resulting solutions were diluted to 40 ml with double-distilled water and filtered. Heavy metal concentrations were then determined using a SHIMADZU AA-7000 atomic absorption spectrophotometer, with results expressed in mg/kg dw (Raoof & Kadhum, 2024).

Health Risk Assessment

The U.S. Environmental Protection Agency (USEPA) health risk assessment models are widely used to measure the risks of long-term exposure to heavy metals in soil and dust. Inhalation, cutaneous exposure, and unintentional ingestion are used to calculate body absorption. Lead, cadmium, zinc, and copper have been linked to neurological and hematological diseases, liver damage, osteoporosis, and extended exposure, while their carcinogenic potential is uncertain. Research shows that children are more vulnerable to non-carcinogenic risks than adults, thus they should be prioritized. (He, et al., 2021). The risk assessment models are as follows:

- $H\,Q^i_{\text{ingestion}} = \frac{C_i \times IR_S \times EF \times ED}{BW \times AT \times R\,f\,D_{\text{ingestion}}} \times 10^{-6}$
- $H\,Q^i_{\text{dermal}} = \frac{C_i \times ABS \times EF \times ED \times SA \times AF}{BW \times AT \times R\,f\,D_{\text{dermal}}} \times 10^{-6}$
- $H\,Q^i_{\text{inhalation}} = \frac{C_i \times IR_a \times EF \times ED}{BW \times AT \times PEF \times R\,f\,D_{\text{inhalation}}}$
- $H\,Q(i) = H\,Q^i_{\text{ingestion}} + H\,Q^i_{\text{dermal}} + H\,Q^i_{\text{inhalation}}$
- $\text{HI} = \sum H\ Q(i)$

Assessment of noncarcinogenic health hazards from heavy metal exposure by inhalation, skin contact, and oral intake requires the following factors. Under this structure:

The individual noncarcinogenic risk (unitless) for each exposure route—unintentional oral intake, skin contact, and inhaling—is assessed using HQ(i) ingestion, dermal, and inhalation.

Ci measures heavy metal i in soil or dust in milligrams per kilogram. HQ(i) is the overall estimated risk for health impacts from all three exposure routes.

Oral exposure intake rate (IRa) is expressed as mg·day−1, inhalation rate (IRa) as m3·day−1), skin surface area (SA) as cm·day−1), frequency of exposure (EF) as days annually, duration (ED) as years, skin adhesion factor (AF) as milligrams per square centimeter, and skin absorption factor (ABS) as units of one.

We utilized default values for parameters in this study: IRS = 200 mg·day−1, IRa = 7.6 m·day−1, EF = 350 days·year−1, ED = 6 years, SA = 2800 cm·day−1, AF = 0.2 mg·cm−2, and ABS = 0.001. The research now considers two more factors: BW (average children's body weight at 15 kg) and AT (average exposure from 6 × 365 days, or 6 years).

Additionally, the daily reference dosage for heavy metals is RfD (mg·kg−1·day−1), with particular values in Table 1. HI represents the cumulative health risk to children from heavy metals.

Results and Discussion

Heavy metal in dust and soil

The initial raw data regarding heavy metal distribution in hospital environments was previously presented at the ICSDCC 2026 conference Table 1. The analysis of heavy metal concentrations in the dust and soil of five healthcare facilities in Al-Diwaniyah revealed varied levels of contamination influenced by urban activity and medical waste. Lead (Pb) concentrations were most prominent in dust at Al-Diwaniya Hospital (44.20 mg/kg), likely due to high traffic density, while soil levels across all sites remained below international CCME standards despite exceeding background levels at certain locations. Cadmium (Cd) levels in both matrices consistently exceeded the background concentration of 0.12 mg/kg, peaking in the soil at Al-Dagharah Hospital (1.02 mg/kg), though they stayed within safe regulatory limits. Mercury (Hg) showed higher accumulation in dust than in soil, particularly at Second Al-Sadr Hospital (0.767 mg/kg), indicating localized urban or medical inputs. Zinc (Zn) concentrations reached a high of 201.50 mg/kg in the soil of the Maternity and Children's Hospital, marginally surpassing the CCME and ISQV-Low threshold of 200 mg/kg. Notably, Nickel (Ni) levels frequently exceeded the CCME safety limit of 50 mg/kg, with Al-Diwaniya Hospital recording the highest soil concentration at 107.77 mg/kg, while Chromium (Cr) remained within safe background and international limits across all sampled healthcare environments.

Table 1: The concentration of heavy metals (mg/kg) in dust and soil of hospitals

Locations	**Pb (dust)**	**Cd (dust)**	**Hg (dust)**	**Zn (dust)**	**Cu (dust)**	**Cr (dust)**	**Ni (dust)**
Al-Diwaniya hospital	44.20	0.33	0.4	35.64	55.31	35.19	84.22
Maternity and Children's Hospital	27	0.52	0.55	123.96	53.9	26.08	52.89
Second Al-sadar Hospital	19.83	0.87	0.767	103.90	35.64	29.05	45.66
Third Al-sadar Hospital	14.28	1.02	0.331	68.17	34.19	37.71	54.40
Al-Dagharah hospital	3.29	0.88	0.147	128.67	32.80	30.77	51.89
	Pb (soil)	**Cd (soil)**	**Hg (soil)**	**Zn (soil)**	**Cu (soil)**	**Cr (soil)**	**Ni (soil)**
Al-Diwaniya hospital	23.86	0.82	0.10	58.04	37.54	53.2	107.77
Maternity and Children's Hospital	31.32	0.70	0.001	201.50	66.22	21.27	45.85
Second Al-sadar Hospital	18.41	0.97	0.2041	92.48	67.2	25.71	28.40
Third Al-sadar Hospital	22.20	0.71	0.370	78.64	42.06	23.48	62.34
Al-Dagharah hospital	31.67	1.02	0.30	87.13	30.93	29.67	74.42
Hong Kong's ISQV-Low	75mg/kg	1.5mg/kg		200mg/kg	65mg/kg	80mg/kg	40mg/kg
Hong Kong's ISQV-High	218mg/kg	9.6mg/kg		410mg/kg	270mg/kg	370mg/kg	
CCME	600mg/kg	22mg/kg	24mg/kg	200mg/kg	63mg/kg	64mg/kg	50mg/kg
Background Concentration	28mg/kg	0.12mg/kg		74mg/kg	26mg/kg	94mg/kg	27mg/kg

Health Risk Assessment

Non-Cancer Health Risk Assessment

The non-cancer health risk assessment examined heavy metal exposure risks via ingestion, inhalation, and skin contact. HQ values for each route were the assessment's basis.

Exposure Pathways Analysis

varied exposure pathways yielded varied HQ values. Since eating had a greater hazard quotient than inhalation and skin contact, it seems to be the predominant pollutant exposure route in the research area. The enormous quantity of contaminants that enter the body via food may explain it.

However, inhaling had lower HQ values. Due to air dilution and dispersion, poisons may not reach the respiratory system as effectively.

Dermal contact had the lowest hazard quotient of the three exposure pathways. This is because skin absorbs contaminants inefficiently.

Element-Specific Risk Assessment

Heavy metals in dust and soil samples from Diwaniyah City hospitals were assessed for non-cancer health hazards. Most elements studied (Cd, Pb, Zn, Cu, and Cr) had hazard quotients < 1. Therefore, exposure to these components at the research locations does not pose substantial non-cancer health risks.

little HQ values in hospitals indicate little pollution or metal sources.

Mercury (Hg) has the greatest hazard quotient. Mercury HQ levels over 1 at Al-Sadr II Hospital and near the danger threshold elsewhere may provide a non-carcinogenic health concern.

Mercury levels may be higher due to its usage in healthcare and research institutions, poor ventilation, and dirty dust.

Mercury was the most dangerous element examined, while all others were below acceptable levels. Continuous monitoring, especially for chemically volatile or harmful compounds like chromium and mercury, is suggested to preserve human health. (Ahmed Ghazi Atiya AL-Shammary & Mahmoud Fadhil Al-Jomaily, 2024) (He, et al., 2021).

Table 2: Health Risk Assessment of heavy metals in dust of Al-Qadisiyah hospitals

Metal	Site	HQ_ING	HQ_INH	HQ_DERM	HI
	Diwaniya	0.054246575	3.16122E-06	0.000801644	0.05505138
	Maternity	0.000237443	4.98132E-06	0.000473699	0.000716123
Cd	II Al-Sader	0.00039726	8.33413E-06	0.000792534	0.001198129
	III Al-Sader	0.017835616	9.77105E-06	0.000929178	0.018774566
	Dagharah	0.000401826	8.42993E-06	0.000801644	0.0012119
	Diwaniya	0.001513699	3.01234E-07	0.000603966	0.002117966
	Maternity	0.000924658	1.84011E-07	0.000368938	0.00129378
Pb	II Al-Sader	0.00067911	1.35146E-07	0.000270965	0.000950209
	III Al-Sader	0.000489041	9.73216E-08	0.000195127	0.000684266
	Dagharah	0.000112671	2.24221E-08	4.49558E-05	0.000157649
	Diwaniya	0.005917808	1.18356E-06	0.000236121	0.006155112
	Maternity	0.076520548	1.53041E-05	0.00305317	0.079589022
Hg	II Al-Sader	1.051109589	0.000210222	0.041939273	1.093259084
	III Al-Sader	0.453890411	9.07781E-05	0.018110227	0.472091416
	Dagharah	0.201739726	4.03479E-05	0.008049415	0.209829489
	Diwaniya	0.002441096	4.73999E-07	0.00036074	0.00280231
	Maternity	0.008490411	1.64862E-06	0.001254694	0.009746754
Zn	II Al-Sader	0.007116438	1.38183E-06	0.001051651	0.008169472
	III Al-Sader	0.004669178	9.06637E-07	0.000690001	0.005360085
	Dagharah	0.008813014	1.71126E-06	0.001302368	0.010117093
	Diwaniya	0.000252557	2.52557E-07	1.0077E-05	0.000262887
	Maternity	0.000246119	2.46E-07	9.82014E-06	0.000256185
Cu	II Al-Sader	0.00016274	1.6274E-07	6.49332E-06	0.000169396
	III Al-Sader	0.000156119	1.56119E-07	6.22914E-06	0.000162504
	Dagharah	0.000149772	1.49772E-07	5.97589E-06	0.000155897
	Diwaniya	0.013772994	2.73895E-06	0.003663616	0.01743935
	Maternity	0.010207436	2.02989E-06	0.002715178	0.012924644
Cr	II Al-Sader	0.011369863	2.26105E-06	0.003024384	0.014396508
	III Al-Sader	0.014759295	2.93509E-06	0.003925973	0.018688203
	Dagharah	0.012043053	2.39493E-06	0.003203452	0.0152489
	Diwaniya	0.000114967	2.2993E-08	4.60084E-06	0.000119591
	Maternity	3.61627E-05	7.23248E-09	1.44504E-06	3.7615E-05
Ni	II Al-Sader	2.0825E-05	4.16498E-09	8.31742E-07	2.16609E-05
	III Al-Sader	1.86138E-05	3.72275E-09	7.43245E-07	1.93608E-05
	Dagharah	1.42065E-05	2.84129E-09	5.67176E-07	1.47765E-05

Conclusion

This study provides a comprehensive environmental assessment of heavy metal contamination and associated health risks in the healthcare facilities of Al-Diwaniyah, Iraq. The findings demonstrate that urban factors—including heavy traffic and industrial proximity—alongside internal hospital operations contribute to varying levels of metallic pollutants in surrounding soil and dust. While concentrations of Pb, Cd, Zn, Cu, and Cr generally remain within safe regulatory limits, nickel levels frequently surpassed international safety standards, and mercury emerged as the most significant non-carcinogenic risk factor, particularly at Al-Sadr II Hospital. The risk assessment confirms that ingestion is the most dangerous route of exposure, followed by inhalation and dermal contact. To safeguard the health of patients, staff, and visitors, it is recommended that healthcare administrators implement more rigorous waste disposal protocols and enhance indoor ventilation systems to reduce the accumulation of hazardous airborne particles.

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