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Chromium and arsenic in an abandoned open dumpsite soil in Iligan, Philippines: A comprehensive ecological and health risk analysis

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Abstract

Improper municipal solid waste disposal is a critical issue impacting soil quality, mainly through the contamination of heavy metals. This study aims to assess the concentrations of chromium and arsenic in the open dumpsite soil of Iligan City, Philippines, and its impacts on the environment and human health. Currently there is no data on the ecological and human health risks associated with open dumpsites in the Philippines. The results indicated that while chromium concentrations fell within acceptable limits for agricultural use, arsenic concentrations significantly exceeded the maximum permissible concentrations set by regulatory bodies, posing a serious environmental hazard. The potential ecological risk index classifies the area as having a low ecological risk, yet highlighted a severe risk associated with arsenic. Health risk assessments indicated that both adults and children fall within acceptable levels for both non-carcinogenic and carcinogenic risks. Overall, these findings demonstrate a need for targeted environmental management strategies in Iligan City to mitigate heavy metal contamination, especially arsenic, and to protect the health of local populations. Remediation efforts and ongoing monitoring are essential to prevent further ecological damage and safeguard public health, particularly for vulnerable groups like children.

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Introduction

Solid waste management (SWM) is a major concern for many countries (Mavakala, 2022). It is estimated that municipal solid waste (MSW) generation in South Asia, Latin America, and Sub-Saharan Africa will double or triple by 2050, making up to 35% of the world's MSW (World Bank, 2018). Increasing population, urbanization, economic development, and improved living standards in developing countries have led to a significant increase in municipal solid waste generation (Minghua *et al.*, 2009). Improper waste management practices have led to releasing of significant amounts of toxic materials, particularly heavy metals, into the environment, exacerbating environmental concerns. Dumpsites, prevalent in many developing countries, pose a significant risk as they contain an amount of contaminants that can potentially leach into the surrounding soil, including heavy metals like arsenic (As) and chromium (Cr) (Kanmani and Gandhimathi, 2013; Olayiwola *et al.*, 2017). In the Philippines, for instance, which records 14.66 million tons of trash annually, heavy metals in open dumpsites are a significant concern (Ali *et al.*, 2013; Rebuelta-The, 2022). Heavy metals such as As and Cr in dumpsites and their toxic nature and persistence in the environment further raise environmental concerns (Flyhammar *et al.*, 1998; Riber *et al.*, 2005; Sankaran and Ebbs, 2007).

Heavy metal contamination of soil may pose risks and hazards to humans and the ecosystem via direct ingestion or contact with contaminated soil, the food chain (soil-plant-human or soil-plant-animal-human), drinking contaminated groundwater, reduction in food quality (safety and marketability) via phytotoxicity, reduction in land usability for agricultural production resulting in food insecurity, and land tenure issues (McLaughlin *et al.*, 2000; Ling *et al.*, 2007). It can accumulate in fatty tissues, influence the central nervous system, be deposited in the circulatory system, and disturb the proper functioning of internal organs. For instance, chromium (Cr) compounds can be absorbed by the lungs, gastrointestinal tract, and, to a limited extent, intact skin. This absorption can lead to respiratory tract irritation, an increased risk of lung cancer, and various health issues affecting the kidneys, liver, stomach, and blood (Wilbur, 2012). Similarly, arsenic can lead to severe health effects such as chronic arsenic poisoning and an elevated risk of skin cancer through prolonged exposure to contaminated soil, food, and water (World Health Organization). As a result, it is critical to monitor and balance heavy metal concentrations in various environmental media to minimize hazardous effects on biota.

Ecological and health risk assessments are essential tools for evaluating the potential impacts of pollutants (Yu *et al.*, 2022). Analyzing soil for toxic metals is vital for understanding environmental pollution and assessing risks to nearby communities (Kasassi *et al.*, 2008; Akanchise *et al.*, 2020; Aja *et al.*, 2021). However, there is currently no data on the ecological and human health risks associated with open dumpsites in the Philippines. This study aims to investigate the distribution of Cr and As in the soil of the vicinity of the abandoned dumpsite in Iligan City, Philippines, and to pre-assess the associated ecological and health risks. The findings will provide a scientific basis for protecting the soil environment and guiding remediation efforts, contributing to minimal environmental impact and reduced health risks.

This study relies on secondary data for the background values of heavy metals, as obtaining primary data from locations several kilometers away from the sampling site would require additional financial resources that are currently unavailable.

Materials and methods

Study area and sampling procedure

This study was conducted in Iligan City, Philippines, located at approximately 8°12'45"N and 124°14'57"E, with an area of 813.37 km² and a population of 363,115 (Census of Population, 2020). The research took place at the abandoned dumpsite within the Central Materials Recovery and Composting Facility (CMRCF), situated in Sitio

Bangko, Brgy. Bonbonon. The CMRCF covers 12.27 hectares, though only 5 hectares are currently in use, handling up to 80 tons of municipal solid waste per day. The facility initially operated with unsegregated waste dumped in unlined landfills before a synthetic liner was installed in 2014 to prevent groundwater contamination from leachate. It is supposed to handle only the recyclable portion of the solid waste, i.e. residuals from the barangays. It has also the intention of receiving the biodegradable portion of the market waste which is to be feed in the composting facility. However, the city was not able to strictly implement its waste segregation programs resulting to substantial amount of solid waste (organic waste, paper, plastic, glass, metals, textiles, and others) being dumped in the CMRCF whose capacity is way below the amount of wastes it receives.

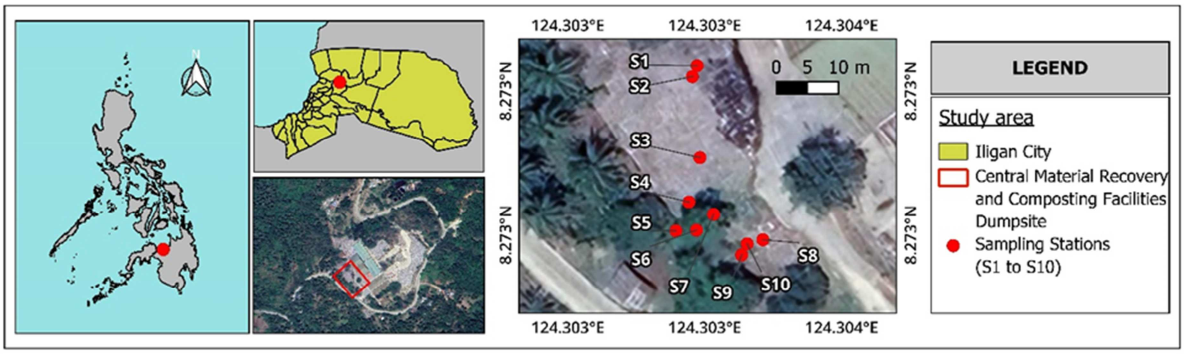

Fig. 1. Location of the sampling sites, central materials recovery and composting facility's dumpsite, Iligan City in the Philippines

The collection of samples was done in September 2023 in the vicinity of the dumpsite with a total area of 247 square meters (see Fig. 1). Sixty 4 m² quadrats were established for systematic sampling and ten of them was selected using weighted random sampling. From each quadrat, nine samples were randomly collected at a depth of 0-20 cm with stainless steel auger and combined to form composite samples based on Sabir *et al.* (2022). The ten sampling sites were labelled S1, S2, S3, S4, S5, S6, S7, S8, S9, and S10 (Fig. 1). Soil samples were air-dried for seven days and homogenized by sieving them through a 2 mm mesh-sized stainless-steel sieve.

Soil sampling analysis

Dried and homogenized soil samples were sent to Omli Workplace Environment Monitoring and Allied Services, Inc., Cagayan de Oro City, Philippines for the analysis of heavy metal content. The arsenic and chromium contents in soil samples were analyzed using manual hydride generation atomic absorption spectrometer (AAS) and direct air-acetylene AAS.

Evaluation of potential environmental risks

The following indices were determined to assess potential environmental risks and contamination levels. These indices are critical for assessing soil pollution and the possible ecological dangers of heavy metals in dumpsites (Sabir *et al.*, 2022; Mavakala *et al.*, 2022; Ekere *et al.*, 2020).

Contamination factor

The contamination factor (CF) was utilized to gauge the concentration of individual heavy metals (HMs) in the soil, a methodology introduced by Hakanson (1980) for assessing HM levels in sediments relative to their natural background values. For each metal, the CF was computed using equation 1, where C_n (mg kg^{-1}) represents the average concentration of the HM in the soil sample and B_v (mg kg^{-1}) signifies the geochemical background value of the HM element in the Earth's crust on average. The CF classification criteria by Hakanson (1980) are shown in Table 1.

$$CF = \frac{C_n}{B_v} \quad (1)$$

Table 1. Pollution indices and their classifications

Contamination factor		Degree of contamination		Geoaccumulation index	
Range	Pollution intensity	Range	Pollution intensity	Range	Pollution intensity
CF < 1	Low contamination	DC < 8	Low degree of contamination	$I_{geo} \leq 0$	Unpolluted
1 ≤ CF <3	Moderate contamination	8 ≤ DC < 16	Moderate degree of contamination	$0 < I_{geo} \leq 1$	Unpolluted to moderately polluted
3 ≤ CF < 6	Considerable contamination	16 ≤ DC < 32	Considerable degree of contamination	$1 < I_{geo} \leq 2$	Moderately polluted
CF ≥ 6	Very high contamination	DC ≥ 32	Very high degree of contamination	$2 < I_{geo} \leq 3$	Moderately to heavily polluted
				$3 < I_{geo} \leq 4$	Heavily polluted
				$4 < I_{geo} \leq 5$	Heavily to extremely polluted
PLI		E_{ri}		PERI	
Range	Pollution intensity	Range	Risk Factor	Range	Ecological risk intensity
PLI < 1	No pollution	$E_{ri} < 40$	Low risk	PERI < 150	Low ecological risk
1 < PLI < 2	Moderate pollution	$40 \leq E_{ri} < 80$	Moderate risk	150 ≤ PERI < 300	Moderate ecological risk
2 < PLI < 3	Heavy pollution	$80 \leq E_{ri} < 160$	Considerable risk	300 ≤ PERI < 600	Considerable ecological risk
PLI > 3	Extremely heavy pollution	$160 \leq E_{ri} < 320$	High risk	PERI ≥ 600	Very high ecological risk
		$E_{ri} \geq 320$	Very high risk		

Table 2. Parameters used to calculate the chronic daily intake (CDI) of heavy metals by adults and children (in mg kg^{-1} d^{-1})

Parameter	Interpretation	Units	Values	
			Adult	Children
C	Heavy metal concentration in soil	mg kg^{-1}	Observed concentration	Observed concentration
	Ingestion rate			
IngR	Exposure frequency	mg d^{-1}	100	200
EF	Exposure duration	d yr^{-1}	350	350
ED	Body weight	yr	30	6
BW	Average time	kg	70	15
AT	Exposed skin area	d	25500	25500
SA	Soil adhere factor	d	5800	2800
AF	Fraction of the applied dose of	mg cm^{-2} d^{-1}	0.07	0.2
ABS	the HM absorbed across the skin	-	0.001	0.001
	Inhalation rate			
	Particle emission factor			
InhR		m^3 d^{-1}	20	7.3
PEF		m^3 kg^{-1}	1.36×10^9	1.36×10^9

Degree of contamination

Degree of contamination (DC) served as an investigative tool for simplifying pollution control, as developed by Hakanson (1980). The DC was applied to assess the extent of pollution in a specific zone of a site, following the methodology introduced by Hakanson (1980). Its calculation involved summing the contamination factors of all analyzed heavy metals, with n representing the number of analyzed HMs (equation 2). The different categories of DC, as recommended by Hakanson (1980), are outlined in Table 1.

$$DC = \sum_{i=1}^{n} CF \quad (2)$$

Pollution load index

Pollution load index (PLI) proposed by Tomlinson (1980) was used to assess the level of soil pollution for the entire site. It was determined using equation 3 where n is the number of HMs studied. Table 1 shows the contamination levels based on the PLI and their interpretation (Tomlinson, 1980).

$$PLI = n\sqrt{(CF1 \times CF2 \times CF3 \times \ldots\ldots \times CFn)} \quad (3)$$

Geoaccumulation index

Geoaccumulation index I_{geo} values are commonly used to assess heavy metal contamination in soil by comparing the concentration of heavy metals in the topsoil to their background levels in the geochemical context of the soil (Sheijany *et al.*, 2020). Classification of the I_{geo} index is shown in Table 1.

$$I_{geo} = \log_2 \left[\frac{C_n}{1.5 \times B_v}\right] \quad (4)$$

Where:

C_n = concentration of metals (mg kg^{-1} DW)

B_v = geochemical background value, which represents the typical or naturally occurring concentration of the corresponding metal *n* in the environment (mg kg^{-1} DW)

Potential ecological risk

Potential ecological risk (PERI) is an ecological risk factor proposed by Hakanson (1980) to quantify the ecological risk potential for a contaminant like heavy metal. The potential ecological risk index (PERI), developed by Hakanson (1980), was used to assess the negative effects of pollutants on the environment and individuals. The methodologies covered a wide range of disciplines for analyzing ecological hazards caused by hazardous metals, as indicated by Sabir *et al.* (2022). The primary role of the model was to prioritize metals based on their toxicity, as noted by Cao *et al.* (2022). The PERI was calculated using equations 5 and 6.

$$E_{ri} = T_{ri} \times CF \quad (5)$$

$$PERI = \sum_{i=1}^{n} E_{ri} \quad (6)$$

The following equation defines PERI as "the sum of all risk values posed by HMs in soil," whereas E_{ri} represents the monomial ecological risk value. Where T_{ri} is the toxic-response factor of a single element and CF is the contamination factor of element i (Hankanson, 1980; Weihua *et al.*, 2010; Islam *et al.*, 2014). It was created to calculate the possible harm posed by HMs by specifying the threshold limit and determining how sensitive the environment is to the associated metals (Sabir *et al.*, 2022).

Potential human health risk assessment

A health risk assessment was conducted to evaluate the potential risk of human exposure to heavy metals (HMs), following the methodology outlined by the United States Environmental Protection Agency (USEPA). As described by Zhang *et al.* (2022), the health risk assessment comprises hazard identification, exposure assessment, dose-response analysis, and risk characterization.

Chronic daily intake

Potential human exposure to HMs was identified through ingestion, inhalation, and dermal contact. To estimate health risk, equations 7 to 9 were employed to calculate the chronic daily intake (CDI) of HMs through these exposure routes according to Obiri-Nyarko *et al.* (2021). This comprehensive approach enables the assessment of potential health risks associated with human exposure to heavy metals in the study area.

$$CDI_{ing} = C\left(\frac{IngR \times EF \times ED}{T \times BW}\right) \times 10^{-6} \quad (7)$$

$$CDI_{inh} = C\left(\frac{InhR \times EF \times ED}{AT \times PEF \times BW}\right) \quad (8)$$

$$CDI_{derm} = C\left(\frac{SA \times ED \times AF \times ABS \times EF}{AT \times BW}\right) \times 10^{-6} \quad (9)$$

Where CDI_{ing}, CDI_{inh}, and CDI_{derm} represent the chronic daily intake of heavy metals (HMs) through ingestion, inhalation, and dermal contact, respectively, measured in mg kg^{-1} d^{-1}. C denotes the concentration of HM in the soil (mg kg^{-1}), IngR is the ingestion rate (mg d^{-1}), EF is the exposure frequency (d yr^{-1}), ED is the exposure duration (yr), BW is the body weight of the exposed individual (kg), AT is the period over which the dose is averaged (d), InhR is the inhalation rate (m^3 d^{-1}), PEF is the particulate emission factor (m^3 kg^{-1}), SA is the exposed skin area (cm^2), AF is the soil adherence factor (mg cm^{-2} d^{-1}), and ABS is the fraction of the applied dose absorbed across the skin. In Table 2, the parameters and their corresponding values are presented according to Sabir *et al.* (2022), serving as the basis for calculating the CDI of HMs through the various exposure pathways.

Table 3. The reference doses (RfD) and carcinogenic slope factors (CSF) used in health risk assessment

Elements	RfD (mg kg^{-1})			CSF (mg kg^{-1} mg^{-1})			Reference
	Ing	Derm	Inh	Ing	Derm	Inh	
As	3.00E10^{-4}	1.23E10^{-4}	3.01E10^{-4}	1.5	3.66	15.1	(Kamunda *et al.*, 2016)
Cr	3.00E10^{-3}	2.86E10^{-5}	6.00E10^{-5}	0.5	20	4.10E10^{1}	(Aa *et al.*, 2022)

Ing = Ingestion; Derm = Dermal; Inh = Inhalation

Table 4. Descriptive statistics of the concentrations of As and Cr of the soil samples

Sample	As	Cr
n	10	10
Mean ± std	27.35 ± 1.68	24.25 ± 7.32
95% Confidence Interval	(26.14, 28.55)	(19.01, 29.48)
Bv (mg kg^{-1})	1.9	90
Maximum allowable content (mg kg^{-1})	15-20	75-100
Food and Agriculture Organization limit (2005)	10	150

Carcinogenic and non-carcinogenic risks

Using the Chronic Daily Intake (CDI), both carcinogenic and non-carcinogenic health risks to humans were evaluated. The Hazard Quotient (HQ) for each heavy metal was calculated by comparing the CDI to the corresponding reference dose, as shown in equation 10 to assess the non-carcinogenic health hazard. This approach is consistent with the methodology described by Obiri-Nyarko *et al.* (2021). Hazard Quotient (HQ) signifies the daily exposure to heavy metals (HMs) in humans that is unlikely to pose a significant risk of adverse effects over a lifetime, as defined by the USEPA. To evaluate the collective non-carcinogenic health hazard, the HQ values for each HM across all exposure pathways were totalled, resulting in a Hazard Index (HI) as expressed in equation 11. The carcinogenic risk (CR) was determined by multiplying the Chronic Daily Intake (CDI) by the corresponding cancer slope factor (CSF) (equation 12). The Total Carcinogenic Risk (TCR) was then computed as the sum of risks from all exposure pathways for all individual metals (equation 13).

$$\mathrm{HQ} = \frac{\mathrm{CDI}}{\mathrm{RfD}} \tag{10}$$

$$\mathrm{HI} = \sum \mathrm{HQ} \tag{11}$$

$$\mathrm{CR} = \mathrm{CDI} \times \mathrm{CSF} \tag{12}$$

$$\mathrm{TCR} = \sum(\mathrm{CDI} \times \mathrm{CSFing}) + (\mathrm{CDI} \times \mathrm{CSFinh}) + (\mathrm{CDI} \times \mathrm{CSFderm}) \tag{13}$$

The reference dose (RfD) is expressed in mg kg^{-1} d^{-1}, while the carcinogenic slope factor (CSF) is denoted in kg d mg^{-1}. These terms pertain to the recommended daily intake for non-carcinogenic effects and the slope of the dose-response curve for carcinogenic substances, respectively (Obiri-Nyarko *et al.*, 2021). The specific values for RfD and CSF corresponding to different exposure pathways for the metals are detailed in Table 3. According to Essien *et al.* (2022), HI < 1 represents a safe range, and HI > 1 shows the potential for non-carcinogenic hazards. Moreover, if the TCR value lies between 1×10^{-6} and 1×10^{-4}, it demonstrates an acceptable or tolerable risk for human health (Xingmei *et al.*, 2013). In regulatory terms, TCR $\leq 1.0 \times 10^{-6}$ represents virtual safety, and TCR $\geq 1.0 \times 10^{-4}$ indicates a potentially great risk (Huang *et al.*, 2019).

Statistical analysis

For the statistical analysis, the results of the ecological risk indices were tested using one-sample t-test to determine if the mean values significantly differ from the known classification in Table 1.

Results and discussion

Chromium and arsenic levels of Iligan City dumpsite soil

The descriptive statistics about the heavy metal concentration of the soils is presented in Table 4. To determine the suitability of the soils for agriculture, the concentrations of HMs in the soils were also compared with the maximum allowable concentrations (MAC). The 95% confidence interval for Cr is from 19.01 mg kg^{-1} to 29.48 mg kg^{-1}. This provides evidence that, at the 5% level of significance, the average concentration of Cr is below the maximum allowable concentration for agricultural soils (75-100 mg kg^{-1}). This means that the area is within a safe range for Cr concentration. Meanwhile, the 95% confidence interval for average concentration of As is between 26.14 mg kg^{-1} and 28.55 mg kg^{-1}. At the 5% level of significance, the average concentration of As significantly exceeded the MAC according to USEPA (see Table 4).

Excessive uptake of As is harmful to various crops; even its minimum quantity causes a diversity of toxic effects on plants. Plants can also be affected by As through stunted roots, withered leaves, reductions in photosynthetic pigment, yellowing of leaves, and reduced chlorophyll (Chl), thus affecting plant metabolism (Gupta, 2020). Based on these results, the soil in the dumpsite is not suitable for agriculture because of the high concentration of As. Among the two heavy metals, the values of As is more than four times the background value.

In fact, according to the Food and Agriculture Organization (FAO), the concentration values of As is beyond the precautionary limit value (Table 4) which it is likely to have a negative impact on human health or environment. Thus, such serious pollution situation should be highly valued. And it has proved to a certain degree that health risk assessment is necessary.

Table 5. Comparison of chromium and arsenic levels in the vicinity of dumpsite soil to the other countries

Country	Location	Environment	Concentrations		References
			As	Cr	
South-Western Nigeria	Igando, Lagos State	Urban	63.24	38.17	Abiaziem *et al.* (2022)
Nigeria	Ugwuaji, Enugu State	City/Urban	ns	22.60	Ekere *et al.* (2020)
Nigeria	Lagos	Urban	7.29	56.74	Odukoya (2015)
Pakistan	Peshawar City	City/Urban	ns	315	Sabir *et al.* (2022)
Iran	Rasht	Urban	10.48	19.08	Sheijany *et al.* (2020)
Democratic Republic of Congo	Kalamu, Kinshasa	City/Urban	0.46	6.08	Mavakala *et al.* (2022)
Democratic Republic of Congo	Limete, Kinshasa	Urban	0.57	9.91	Mavakala *et al.* (2022)
Philippines	Talavera, Nueva Ecija	Rural	2.63	69.64	Santos *et al.*, 2021
Philippines	Iligan City	City/Urban	27.35	24.25	This study

ns, not studied

Table 5 provides a comparative analysis of Cr and As levels in Iligan City dumpsite soil alongside findings from various global studies. The arsenic concentration is recorded at 27.35 mg kg^{-1}, making it the second highest among the locations listed in Table 5, while Abiaziem *et al.* (2022) reported an even higher concentration of 63.24 mg kg^{-1} in their study of the dumpsite soil. This stark contrast highlights the varying levels of arsenic contamination across regions. For chromium, the levels found in this study are higher than those reported by Ekere *et al.* (2020) in Ugwuaji, Nigeria, Mavakala *et al.* (2022) in Limete and Kalamu, Democratic Republic of Congo, and Sheijany *et al.* (2020) in Rasht, Iran. However, the chromium concentration in this study is lower than the findings of Abiaziem *et al.* (2022), Odukoya (2015), and Sabir *et al.* (2022) (Table 7). Additionally, the research by Santos *et al.* (2021) in Talavera, Philippines, showed chromium levels of 69.64 mg kg^{-1}, significantly higher than this study, despite their arsenic levels being much lower at 2.63 mg kg^{-1}. These findings underscore the diverse contamination profiles of heavy metals in different regions, emphasizing the need for targeted environmental management strategies in Iligan City to mitigate the risks associated with heavy metal exposure. The distribution of metals in soil can vary widely due to the heterogeneous nature of waste found in dumpsites (Mavakala *et al.*, 2022). Additionally, the physicochemical properties of soil and sediment can affect how heavy metals are distributed in contaminated areas.

Ecological risk indices

Geoaccumulation index for Cr and As in the soil

The values of I_{geo} are presented in Table 6. The mean values of the I_{geo} in ten sampling sites were in the following order As > Cr. The soil is heavily polluted with As ($3 < I_{geo} \leq 4$) whereas chromium is assessed as unpolluted ($I_{geo} \leq 0$). The I_{geo} results for Cr may confirm that Cr may have a natural origin in the soil of this region. Soleimannejad *et al.* (2016) reported a similar trend for the I_{geo} of As in the dumpsite which was located in Ghaemshar, Iran. Also, Odukoya (2015) made a similar observation in two dumpsites in Lagos, Nigeria.

According to Nyika *et al.* (2019), dumpsite have a high potential for leachate production due to weather conditions. Leachate production from the waste, such as dyes and pigments, medical waste, pesticides, and ash from hospital waste incineration, can be the origin of As.

Table 6. Ecological risk indices of the studied soil

	Parameters		Potential ecological risk
	As	Cr	
Mean concentrations (mg kg^{-1})	27.35	24.25	144.54*
Background values (mg kg^{-1})	1.9	90	
Toxicity factor	10	2	
Contamination factor	14.40*	0.27*	
Degree of contamination	14.67*	-	
Pollution load index	3.94*	-	
Geoaccumulation index	3.26*	-2.48*	
Ecological risk	144.00*	0.54*	

*Significant at 5% level of significance via one-sample t-test. - No calculated data

Contamination factor, degree of contamination and pollution load index of Cr and As in the soil

The CF reveals that the soil is highly contaminated with arsenic, while chromium (Cr) levels are relatively low (Table 6). The overall DC for the two heavy metals examined is moderate, with a value of 14.40, which is close to the threshold for higher pollution intensity (DC of 16 or more). Additionally, the PLI, which provides a composite value to assess the overall pollution status of the soil, is 3.94, suggesting extremely heavy pollution (PLI > 1) primarily driven by the elevated contamination factor of As (Table 6). Akanchise *et al.* (2020) obtained CF > 6 for As in the soil of the abandoned dumpsite in Amakom, suburbs of Kumasi in the Ashanti region of Ghana which is similar to this study. Also, Ekere *et al.* (2020) reported PLI > 1 for the soil of abandoned dumpsite that is similar to the results of this study.

Potential ecological risk

The E_{ri} assessment highlights considerable risk associated with arsenic, with a risk factor between 80 and 160, while the risk from chromium remains low (risk factor below 40). The PERI, which evaluate the potential ecological risk based on the toxicity of contaminants and their concentrations, classifies the area as having low ecological risk, emphasizing the need for monitoring. This is important because although the overall ecological risk is low, the elevated arsenic levels still pose a significant threat to the environment and public health.

Continuous monitoring will ensure that arsenic concentrations do not exceed safe thresholds and allow for early detection of any changes in contamination levels, helping to mitigate potential long-term environmental impacts (WHO). The elevated levels of heavy metals (HMs) support our theory that the dumpsite is being used illegally for both hazardous and non-hazardous waste, which is not permissible under Republic Act 9003 or known as the Ecological Solid Waste Management Act of 2000 in the Philippines. When organic materials like biosolids, livestock manures, compost, and municipal sewage sludge are disposed of in open dumps, they can lead to the accumulation of heavy metals in the soil, including arsenic and chromium. While organic waste typically has lower heavy metal content, ongoing disposal can result in significant accumulation over time. Studies have shown that repeated application of biosolids and manure to land can increase soil concentrations of heavy metals, including arsenic and chromium, leading to long-term contamination (Sharma *et al.*, 2009).

These findings highlight that even abandoned dumpsites, pose significant arsenic contamination risks, aligning with previous research by Akanchise *et al.* (2020) and Ekere *et al.* (2020). Despite being abandoned, the site still requires active management and monitoring to prevent further environmental degradation and protect public health, emphasizing the need for stringent enforcement of waste management regulations.

Table 7. Chronic daily intake (CDI), Hazard quotient (HQ), and Hazard index (HI) for adults and children in soil for non-carcinogenic risk

Receptor pathway		CDI (mg kg^{-1} day^{-1})		HQ		HI
		As	Cr	As	Cr	
Adult	Ingestion	1.61E-05	1.43E-05	5.36E-02	4.75E-03	0.058
	Inhalation	1.18E-08	1.05E-08	3.93E-13	1.75E-14	4.10E-13
	Dermal	6.53E-08	5.79E-08	5.31E-12	2.02E-13	5.51E-12
	Total	1.62E-05	1.43E-05	5.36E-02	4.75E-03	0.058
Children	Ingestion	3.00E-05	2.66E-05	1.00E-01	8.87E-03	0.109
	Inhalation	2.21E-08	1.96E-08	7.34E-13	3.26E-14	7.66E-13
	Dermal	8.41E-08	7.45E-08	6.84E-12	2.61E-13	7.10E-12
	Total	3.01E-05	2.67E-05	1.00E-01	8.87E-03	0.109

Table 8. Carcinogenic risk (CR) for different exposure pathways (ingestion, inhalation, and dermal) and total carcinogenic risk (TCR) for adults and children

Metal	Adult			
	CR_{ing}	CR_{inh}	CR_{derm}	TCR
As	2.41E-05	1.79E-07	2.39E-07	2.46E-05
Cr	7.13E-06	4.30E-07	1.16E-06	8.72E-06
Total	3.12E-05	6.09E-07	1.40E-06	3.33E-05
Metal	Children			
	CR_{ing}	CR_{inh}	CR_{derm}	TCR
As	4.51E-05	3.33E-07	3.08E-07	4.57E-05
Cr	1.33E-05	8.03E-07	1.49E-06	1.56E-05
Total	5.84E-05	1.14E-06	1.80E-06	6.31E-05

Health risks assessment

Table 7 displays the findings of the hazard quotient (HQ) and hazard index (HI), which indicate the non-carcinogenic impacts of HM pollution on human health. For all the heavy metals in all the pathways, HQ < 1 was found for adults, indicating a safe range for non-carcinogenic risks. Children's observations were similar, suggesting a safe range for non-carcinogenic risks as well. When it comes to non-carcinogenic risks, HI values more than 1 are deemed significant. As per the non-carcinogenic risk criteria, all the metal values under analysis fell within the threshold limits. Sabir *et al.* (2022) reported HI < 1 in the dumpsite soil of the city of Peshawar in Pakistan that is similar to the result of this study. However, due to their frequent contact with dirt, municipal employees and other local rubbish, data also show that the ingestion pathway, which is followed by the dermal pathway, is the primary cause of non-carcinogenic health concerns in both adults and children. According to Table 7, the inhalation pathway contributes the least to the non-carcinogenic risk. The same trend has been reported by Sabir *et al.* (2022).

Carcinogenic risk estimations were done both for As and Cr due to their high toxicity levels. The total risk was calculated by summing the individual CR for all the exposure pathways (Table 8). The TCR for adults was 3.33 $\times 10^{-5}$, whereas the TCR for kids was 6.31 $\times 10^{-5}$. The permissible range for these values is between 1.0 $\times 10^{-6}$ and 1.0 $\times 10^{-4}$. The current study's results showed that none of the TCR values exceeded the safe limit that is similar to the study of Obiri-Nyarko *et al.* (2021). But as the TCR shows, As contributed more to the risk of cancer (73.82% in adults and 72.42% in children) more than chromium did. Arsenic has also been linked in numerous studies to increased risks of cancer and non-cancerous outcomes at HM-contaminated areas (Huang *et al.*, 2019; Ekere *et al.*, 2020; Obiri-Nyarko *et al.*, 2021).

Its comparatively high concentration in soil and/or low RfD may be the cause of this. Human exposure to high levels of As has been linked to a number of harmful health outcomes, such as cancers of the skin, lungs, bladder, prostate, liver, and other organs, as well as circulatory, neurological, dermatological, and cardiovascular disorders (Tchounwou *et al.*, 2018). Since children are more susceptible to the health impacts of As than adults are, even at extremely low levels, the comparatively high arsenic HI and TCR values for children raise serious concerns about their health (Daston *et al.*, 2004). These findings support existing research, demonstrating that non-carcinogenic risks from heavy metal exposure remain within safe limits for both adults and children, with ingestion and dermal pathways being the primary routes of concern. Moreover, the significant carcinogenic risk posed by arsenic, particularly to children, highlights a critical need for urgent, targeted interventions to mitigate the long-term health impacts in contaminated areas.

Despite high contamination indices like the contamination factor, degree of contamination, geoaccumulation index, and pollution load index suggesting significant environmental risk, the health risk assessment can still indicate a safe range for human exposure. This discrepancy arises because ecological risk indices reflect environmental contamination levels, whereas health risk assessments focus on actual human exposure and toxicity (USEPA). One key factor is the difference between the potential for contamination and the actual bioavailability of harmful substances, such as arsenic, in the environment. Arsenic in soil or water may not always be in a bioavailable form, meaning that it might not be easily absorbed by the human body (Caussy, 2003). The duration and frequency of exposure also play a crucial role; health risks are often assessed based on chronic exposure scenarios, and short-term or infrequent exposure may not pose significant health threats (Agency for Toxic Substances and Disease Registry (US), 2007). Additionally, health risk assessments often incorporate safety margins, which provide a buffer to account for uncertainties in exposure, toxicity, and population variability (Eckerman, 1998).

Conclusion

This study assessed the concentrations of chromium and arsenic in the open dumpsite soil of Iligan City, revealing critical findings regarding environmental safety and public health.

While chromium concentrations were within acceptable limits for agricultural use, arsenic levels significantly exceeded the maximum allowable concentrations set by regulatory bodies, posing a serious environmental hazard. Specifically, the mean concentration of arsenic was more than four times the background value and well above precautionary limits established by FAO, highlighting the urgent need for remediation.

Ecological risk indices indicated moderate contamination overall but showed a severe risk linked to arsenic. The Pollution Load Index (PLI) categorized the dumpsite as extremely polluted, primarily due to arsenic, while chromium levels were considered unpolluted. These findings were further supported by Igeo, which confirmed heavy pollution from arsenic and an unpolluted status for chromium.

Health risk assessments showed that both adults and children were within safe ranges for non-carcinogenic risks based on the Hazard Quotient (HQ). However, Total Carcinogenic Risk (TCR) revealed concerning levels, especially regarding arsenic exposure, with heightened vulnerability for children. These results emphasize the need for targeted environmental management strategies to mitigate arsenic contamination and protect public health, particularly among vulnerable populations like children.

This study is one of the first to assess ecological and health risks in the abandoned open dumpsite in the Philippines specifically in Iligan City, providing valuable insights into the environmental and health impacts of improper waste disposal. Despite the limited sampling area, the findings offer essential data for broader regional assessments and stress the immediate need for intervention. Although the contamination levels of chromium were lower than those found in previous studies, the elevated arsenic concentrations present a serious risk, especially considering their potential long-term impacts on the environment and public health.

The study provides critical baseline data on heavy metal concentrations, ecological impacts, and both carcinogenic and non-carcinogenic risks, forming a solid foundation for future research and remediation efforts. Ongoing monitoring is essential to track contamination progression, safeguard vulnerable groups, and guide future interventions to prevent further ecological and health damage. Additionally, the study recommends expanding the sampling area and analyzing other heavy metals, such as mercury, lead, and cadmium, around the CMRCF.

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