Carcinogenic and non-carcinogenic health risk assessment of Arsenic in indoor dust from an e-waste contaminated area in Thailand

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Abstract

This study reports arsenic (As) contamination in indoor dust (n = 96) and evaluates both non-carcinogenic and carcinogenic health risks to residents living in an e-waste contaminated area in Thailand during the cool, dry and wet seasons. The mean concentration of As in domestic dust across all three seasons was 0.6 mg/kg. The highest As level (4.4 mg/kg) was detected in residential dust collected from the living room of house 4 during the cool season. Interestingly, the lowest dust As concentration was observed during the wet season, possibly due to reduced e-waste recycling activities during the COVID-19 outbreak in the study area. A one-way ANOVA indicated no statistically significant differences in dust As concentrations among the three seasons in most of the investigated households. These findings suggest that indoor dust As levels were mainly influenced by the quantity of recycled e-waste, recycling intensity and indoor environmental conditions. Human health risk assessment indicated that the non-carcinogenic risk of inorganic arsenic (iAs) through dust ingestion was within acceptable limits for both adults and children. The carcinogenic risk (CR) values for children ranged from 2.6×10^{-5} to 4.1×10^{-5}, whereas those for adults ranged from 2.8×10^{-6} to 4.4×10^{-6}, indicating an acceptable cancer risk according to the US EPA guidelines. Overall, children were found to be more vulnerable to arsenic exposure than adults due to higher dust ingestion rates and behavioral characteristics. These findings highlight the importance of monitoring arsenic contamination in indoor environments of e-waste recycling areas to reduce potential health risks to local residents.

Keywords: Health risk assessment, Carcinogenic, Non-carcinogenic risk, Arsenic, Indoor dust, Electronic waste (e-waste)

Introduction

The global increase in electronic waste (e-waste) has become a critical environmental and public health issue (Lundgren, 2012). E-waste contains toxic heavy metals such as arsenic (As), which can easily be released into the environment, especially in areas where informal processing is carried out without *appropriate and sustainable e-waste management* (Andeobu et al., 2023). In Thailand, particularly in some provinces of the northeastern region, the informal crude e-waste recycling at family-run backyard workshops of the residences has remained a common activity, where there is a risk of heavy metal contamination (Kuntawee et al., 2020).

Indoor dust serves as a principle sink of several air pollutants including heavy metals from both indoor and outdoor sources (Zhang et al., 2018). Children and adults spend an average of 75% and 88% of their time in indoor environment, respectively (United States Environmental Protection Agency [US EPA], 1997); hence, the contents of heavy metals in indoor dust is primary to the public health. In family-run e-waste workshops, the contaminated indoor dust are *substantially* emitted from the e-waste and can additionally absorb and accumulate heavy metals like As (Andeobu et al., 2023). The occupants are exposed to the metals through occupational and environmental sources via three crucial routes including inhalation of particles and air, ingestion and skin contact (Andeobu et al., 2023). Adverse effects associated with As exposure include skin lesions and alterations, diabetes, developmental and renal toxicity, cardiovascular disease, gastrointestinal symptoms, peripheral neuropathy and cancer of skin and internal organs such as lung (Andeobu et al., 2023).

In this research, the study area is one of the heaviest e-waste contaminated areas in Thailand (Dvorska et al., 2023a). This study investigated heavy metal pollution and human health risk assessment in a Thai e-waste contaminated area through ingestion of indoor dust during the cool, dry and wet seasons. The objectives of this study were: (1) to investigate the presence of As in house dust sampled from the e-waste contaminated area in northeastern Thailand during the cool, dry and wet seasons; (2) to determine the exposure rates due to As via house dust ingestion for both adults and children during the cool, dry and wet seasons; and (3) to evaluate the carcinogenic and non-carcinogenic risks posed by As during the cool, dry and wet seasons.

Research Methodology

This study employed a seasonal cross-sectional design with field-based environmental sampling to investigate heavy metal contamination in indoor dust and associated health risks.

Site and sample description

A total of 96 residential dust samples were taken from bedrooms (n=48) and living rooms (n=48) of 16 monitored dwellings in a sub-district of northeastern Thailand, Kalasin Province, during 23rd-25th December 2019 (cool), 23rd-25th March 2020 (dry) and 5th-7th August 2020 (wet).

Sample collection

Indoor dust samples (n=96) were collected following previously published standardized protocols (Muenhor et al., 2010). In short, 1600 W vacuum cleaners were deployed to sample settled dust into 25 µm pore size nylon socks and were cleaned prior to each sampling to overcome cross contamination. In individual residences, four m^2 of bare floor was vacuumed for four minutes. After sampling, the samples were kept in iceboxes and transported to a laboratory. In the laboratory, all collected dust samples were sieved through a clean 500 µm mesh, homogenized, weighed and transferred to pre-cleaned glass vials in cold storage at -21 ^{0}C until metal analysis.

Analysis of As in dust samples

Dust samples were measured for As levels according to the AOAC Official Method (Latimer, 2016). Briefly, 0.25-0.5 g of each accurately weighed dust sample was placed in a vessel and digested with 10 mL of concentrated nitric acid (HNO_3 69%) at 200 °C using a microwave digestion system (CEM MARS 6). Quantitative analysis of As in the obtained dust extracts were carried out using an Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES; Perkin Elmer, Avio 500) (Latimer, 2016). Method limits of quantification for As was 0.04 mg/kg.

Health risk assessment

In this section, As was evaluated as toxicological reference parameters (e.g., RfD and CSF) that are defined only for inorganic As. Thus, to prevent over-estimation of As-related health risk, an inorganic As:total As ratio of 0.096:1 (Oguri et al., 2013) was applied in the health risk assessment.

Exposure assessment

For non-carcinogenic risk assessment, the chronic daily intake (CDI; mg/kg/day) was estimated using equation 1(US EPA, 2011).

$$CDI = \frac{C \times IR \times CF \times FI \times EF \times ED}{BW \times AT} \qquad \text{(Equation 1)}$$

where C is the concentration of As in dust (mg/kg); IR is the dust ingestion rate (100 and 200 mg/day for adults and children, respectively) (US EPA, 1997; Leung et al., 2008); CF is the unit conversion factor (10^{-6} kg/mg); FI is the fraction of ingested dust assumed to originate from contaminated sources (1.0); EF is the exposure frequency (365 days/year); ED is the exposure duration (70 and 10 years for adults and children, respectively) (Demissie et al., 2024); BW is the average body weight (57.7 kg for adults, and 12 kg for children) (Muenhor et al., 2018); AT is the averaging time for carcinogenic and non-carcinogenic risk (equal to ED × 365 days for all groups) (U.S. EPA, 1989).

Non-carcinogenic risk

Hazard quotient (HQ) was calculated to assess the non-carcinogenic effect of each heavy metal via equation 2.

$$HQ = \frac{CDI}{RfD} \quad \text{(Equation 2)}$$

The reference dose (RfD) value adopted was 0.00006 mg/kg/day for inorganic As (US EPA, 2025a).
Non-carcinogenic risk was determined using the HQ. The HQ ≤ 1 indicates unlikely non-carcinogenic health effects while the HQ > 1 indicates the probability of non-carcinogenic health effects. The HQ > 10 indicates the high non-carcinogenic health risk.

Carcinogenic risk

Oral cancer slope factors (CSF) for different target heavy metals were used to evaluate the carcinogenic risk (CR). Inorganic As were considered carcinogenic heavy metals, with CSF of 31.7 (mg/kg/day) (US EPA, 2025a; Meyers et al., 2025). The cancer risk (CR) was then computed by equation 3.

$$CR = CDI \times CSF \quad \text{(Equation 3)}$$

The CR $\leq 1.0 \times 10^{-6}$ indicates negligible cancer risk whereas the CR $> 1.0 \times 10^{-4}$ suggests the unacceptable cancer risk. Furhtermore, the CR ranging from 1.0×10^{-6} to 1.0×10^{-4} indicates the acceptable cancer risk (US EPA, 1989).

Statistical analysis

All statistical analyses in this study were performed using appropriate statistical software. A significance level of 0.05 was adopted, and p-values less than 0.05 were considered statistically significant.

Results and discussion

Concentrations of As in indoor dust samples

Overall, the mean concentrations of As in indoor dust during all three seasons including cool, dry and wet seasons was 0.6 mg/kg (Table 1), (Figure1). Contents of As in settled dust during the cool and dry seasons varied from <0.04-4.4 and <0.04-3.7 mg/kg, with means of 0.87 and 0.57 mg/kg, respectively (Table 1). Conversely, levels observed in the wet season were comparatively lower, ranging from <0.04-2.1 mg/kg, with average levels of 0.50 mg/kg (Table 1). The highest level of As (4.4 mg/kg) was detected in indoor dust sampled from the living room of house 4 during the cool season. Detailed inspection indicates that the monitored metal contents were primarily influenced by the extent of e-waste recycling activities and the number of electrical and electronic devices processed within the house. The mean concentrations of As in indoor dust reported here were lower than those found in Chinese homes in an e-waste recycling area (Wu et al., 2016) We believe that the lower indoor As contents in the current study could possibly be ascribed to the frequent use of fans as well as open windows and doors in Thai homes in rural areas during the daytime, which provide massive and rapid air exchanges between the investigated residences and the external environments.

A one-way ANOVA showed that As levels in most of the investigated homes during the cool, dry and wet seasons were not statistically significantly different (p > 0.05). Interestingly, the lowest dust concentration of As was presented during the wet season (5^{th}-7^{th} August 2020) owing to the *impact of the COVID-19 outbreak in the study area* on both the e-waste quantity and intensity of e-waste processing activities, a trend noted by Iwegbue et al. (2018) (Iwegbue et al., 2018).

Health risk assessment
Chronic daily intake

In the current study, the chronic daily intake (CDI; mg/kg/day) of inorganic As (iAs) by ingestion of indoor dust during the cool, dry and wet seasons was generated separately for adults and children. The CDI values estimated for adults and children are provided in Table 2. It is evident in Table 2 that the CDIs of iAs during the cool, dry and wet seasons were greater in children than in adults. The results are comparable to those from e-waste recycling workshops in China (Leung et al., 2008).

Non-carcinogenic risk

Table 2 outlines the hazard quotient (HQ) created to estimate the non-carcinogenic risks of iAs in the domestic dust during the cool, dry and wet seasons. As shown in Table 2 and Figure 2, the risk assessment during the cool, dry and wet seasons indicated that children have a higher HQ values than adults, which is consistent with the results from Chinese e-waste workshops and urban dwellings (Leung et al., 2008) Additionally, the HQs among children and adults were all lower than 1, demonstrating no detrimental health effects.

Carcinogenic risk

As shown in Table 2 and Figure 3, the carcinogenic risk (CR) values for iAs in children from ingestion of residential dust during the cool, dry, and wet seasons were 4.1×10^{-5}, 2.6×10^{-5}, and 2.6×10^{-5}, respectively, suggesting an acceptable cancer risk (US EPA, 1989). In contrast, the CR values for iAs in adults from ingestion of household dust during the cool, dry, and wet seasons were 4.4×10^{-6}, 2.8×10^{-6}, and 2.8×10^{-6}, respectively, suggesting a negligible carcinogenic risk (US EPA, 1989). Thus, in the present study, the CR values for iAs in children from ingestion of indoor dust during the cool (4.1×10^{-5}), dry (2.6×10^{-5}), and wet seasons (2.6×10^{-5}) were within the acceptable cancer risk range (10^{-6}–10^{-4}) recommended by the US EPA (US EPA, 1989). In contrast, the CR values for adults were considerably lower, indicating a negligible carcinogenic risk. Overall, the CR values for iAs across all three seasons suggested that children were at greater carcinogenic risk than adults. This difference may be attributed to several factors, including: (a) higher dust exposure among children due to crawling and playing close to the ground as well as frequent hand-to-mouth and object-to-mouth behaviors; (b) greater dust ingestion per unit body weight; and (c) immature detoxification and elimination systems (Andeobu et al., 2023; Somsunun et al., 2023; US EPA, 2025b). These findings are consistent with previous studies conducted in urban environments, such as Chengdu, China, which also reported higher carcinogenic risks from heavy metal exposure in children compared with adults (Leung et al., 2008; Xu et al., 2015; Cheng et al., 2018).

Table 1 Concentrations of As (mg/kg) in house dust samples (n=96) from a Thai e-waste contaminated area.

House	Arsenic (As)			
	Average	Median	Range	SD
1	0.4	0.1	<0.04-1.0	0.4
2	0.6	0.5	<0.04-1.2	0.4
3	0.3	0.3	<0.04-0.9	0.3
4	1.2	0.1	<0.04-4.4	1.8
5	0.4	0.2	<0.04-1.0	0.4
6	0.9	0.1	<0.04-3.7	1.5
7	0.4	0.1	<0.04-1.6	0.6
8	0.3	0.2	<0.04-0.8	0.3
9	0.3	0.1	<0.04-1.2	0.4
10	1.3	1.4	<0.04-1.9	0.6
11	0.5	0.5	<0.04-1.1	0.4
12	1.0	0.3	<0.04-2.7	1.2
13	0.1	0.1	<0.04-0.3	0.1
14	0.5	0.3	<0.04-1.0	0.4
15	0.9	0.5	<0.04-2.9	1.1
16	1.5	1.3	<0.04-3.7	1.3
All studied houses (1-16)	0.6	0.2	<0.04-4.4	0.9

Note: All values below the dl were assumed to be half of the dl for the purposes of computing statistics.

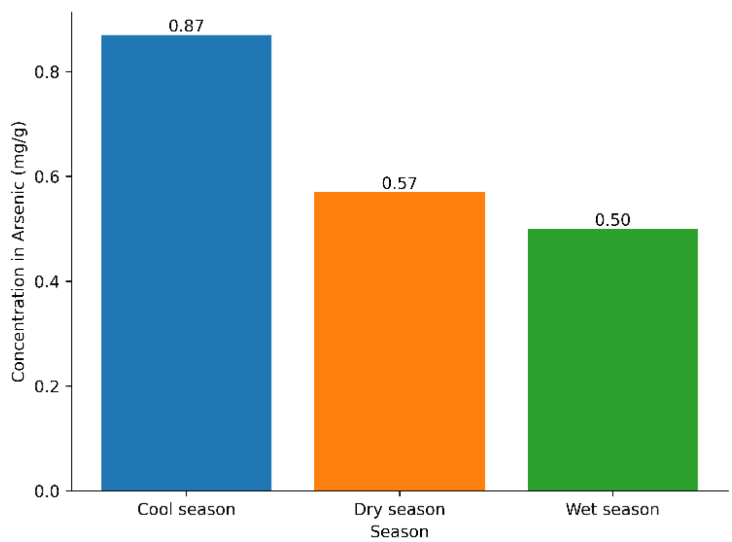

Figure 1 Mean concentrations of As (mg/kg) in house dust samples (n=96)

Table 2 **CDI, HQ, and CR values calculated for adults and children during cool, dry and wet seasons**

Heavy metal study group	iAs Cool season	iAs Dry season	iAs Wet season
Adults			
CDI	1.4×10^{-7}	8.7×10^{-8}	8.7×10^{-8}
HQ	0.002	0.001	0.001
CR	4.4×10^{-6}	2.8×10^{-6}	2.8×10^{-6}
Children			
CDI	1.3×10^{-6}	8.3×10^{-7}	8.3×10^{-7}
HQ	0.02	0.01	0.01
CR	4.1×10^{-5}	2.6×10^{-5}	2.6×10^{-5}

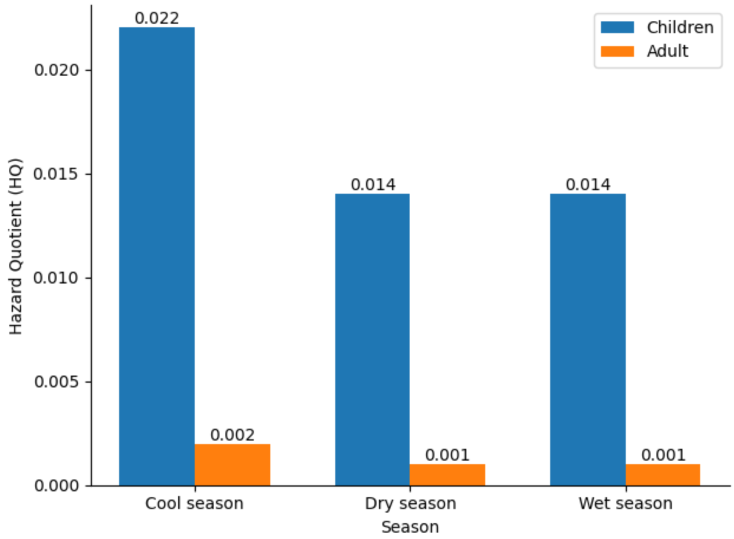

Figure 2 Hazard Quotien (HQ) of iAs in adults and children during cool, dry and wet seasons.

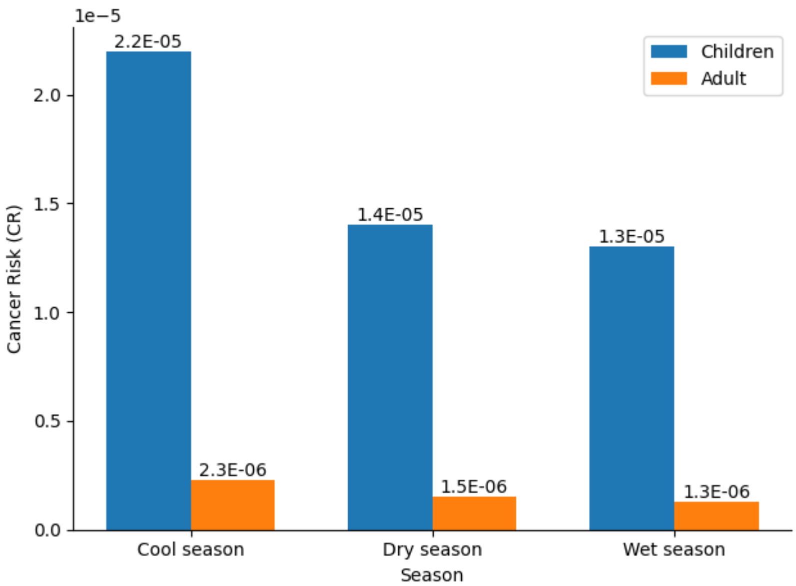

Figure 3 Cancer risk (CR) of iAs (mg/kg) in adults and children during cool, dry and wet seasons.

Conclusions

The present study evaluated arsenic (As) contamination in settled indoor dust and assessed both non-carcinogenic and carcinogenic health risks to Thai adults and children living in an e-waste contaminated area during the cool, dry and wet seasons. The concentrations of As in residential dust were generally lower than those reported in several studies conducted in other countries. A one-way ANOVA indicated no statistically significant differences in dust As concentrations among the cool, dry and wet seasons in most of the studied residences, demonstrating that the number of processed e-waste items, recycling activities and indoor environmental conditions principally contribute to the indoor dust metal levels.

Human health risk assessment suggested that the non-carcinogenic risk of inorganic arsenic (iAs) through dust ingestion was within acceptable limits for both adults and children. The carcinogenic risk (CR) values for children were within the acceptable risk range (10^{-6}–10^{-4}) recommended by the US EPA, whereas the CR values for adults were considerably lower, indicating negligible carcinogenic risk. Overall, children were found to be more vulnerable to arsenic exposure than adults due to higher dust ingestion rates and behavioral characteristics.

The present study justifies further high-quality research on arsenic contamination in both occupational and residential environments, with particular attention to multiple exposure pathways (e.g., dermal contact and dietary intake) and indoor environmental factors influencing arsenic accumulation in residential dust.

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