

# Investigation of heavy metals in indoor dusts of households in an indubitable range from a landfill located in south-western India

Naveen S. Lal<sup>1</sup>, C.T Aravindakumar<sup>2,3</sup>, and Usha K. Aravind<sup>1\*</sup>

<sup>1</sup>School of Environmental Studies, Cochin University of Science and Technology, Kochi, India

<sup>2</sup>School of Environmental Sciences, Mahatma Gandhi University, Kottayam, India

<sup>3</sup>Inter University Instrumentation Centre, Mahatma Gandhi University, Kottayam, India

**Abstract.** Waste treatment plants, landfills, and dump yards are surplus in trash that emits various elements, including heavy metals, into the atmosphere either by human activities or by any fire events. This study investigates the heavy metals in indoor dusts of households situated at various directions and varying distances away from the landfill and its impact on human health and the environment. The concentration of heavy metals in dust samples followed the order (mg/kg): Fe (14905.68) > Mn (377.57) > Cu (275) > Zn (219.41) > Cr (145.91) > Pb (124.86) > Ni (68.89) > Cd (5.58). The contamination factor underscores elevated pollution for Zn and Pb (marker elements) and pollution load index showed contamination in most of the sites. While considering health risk assessments, the Hazard Index (HI) for non-carcinogenic effects on both children and adults indicates values < 1. Carcinogenic effects possessed values in the appreciable category except for dermal exposure for Cd, where the values fell in the acceptable risk category, suggesting no immediate harm to the exposed population. The study postulates that the high pollution index levels may hint at potential future risk. The study also demonstrates the significance of risk assessment formulas for immediate health risk assessment.

## 1 Introduction

Metropolitan expansion, industrial development, and demographic boom have led to a rise in garbage production worldwide, especially in developing nations, where improper waste management has become a significant concern for both humans and the environment. As we all know, the increasing population in urban areas leads to an increase in consumption, which in turn leads to an increase in the generation of waste materials, especially solid waste that is difficult to dispose of. The most prominent and easy method of solid waste disposal is the use of sanitary landfills. Most of the solid wastes generated (E-waste, plastic waste, food waste and all other paper wastes) in urban areas are dumped at landfills, and this landfill acts as a reservoir of harmful pollutants. These pollutants can be released from landfills to the atmosphere due to various activities in landfills such as transit, buildup, squeezing and

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\* Corresponding author: [uka@cusat.ac.in](mailto:uka@cusat.ac.in)

annihilation. Unexpected fires which occur in landfills by internal (heat generation from biological degradation processes, methane generation from anaerobic decomposition of organic waste, spontaneous ignition) and external sources (excessive temperature during summer, sparks from faulty landfill machinery, etc) may also result in emission of pollutants.

The pollutants emitted from the landfills include numerous organic (Dioxins, furans, polycyclic aromatic hydrocarbons, perfluorinated alkyl substances, polymers, BTEX and other hydrocarbons) and inorganic pollutants (crustal elements, heavy metals and gases such as CO, CO<sub>2</sub>, SO<sub>x</sub>, NO<sub>x</sub>). Landfills are abundant sources of heavy metals, and their emission to the atmosphere may lead to exposure to the human population residing nearby, which in turn causes serious health effects to the exposed population. Even though landfill aerosol emissions and their characterisation have been formerly studied, studies on aerosol characterisation in indoor microenvironments surrounding the landfill or at certain distances away from landfills are lacking.

So, in order to address these issues, this study focusses mainly on (a) target analysis of heavy metals present in indoor dust of households nearby and certain range away from a waste treatment plant (treatment plant often remain as landfills or dump yards), (b) assessing the contamination level of the studied households with help of various pollution indices, (c) assessing non-carcinogenic and carcinogenic human health risk of the population residing in the sampled households.

## **2 Materials and Methods**

### **2.1 Study area and sample collection**

The study area consists of a municipal solid waste treatment plant (Brahmapuram Solid Waste Treatment Plant (BSWTP)) located at Brahmapuram (also known as Brahmapuram landfill) and 17 other places encircling the plant altogether, located in the Ernakulam district of Kerala state, India. The study area is shown in Figure 1. Kochi city, known as the financial and economic capital of Kerala, located in the Ernakulam district, generates a huge quantity of waste per year that ends up in the BSWTP.

A total of 17 representative dust samples were taken from households of various directions (north, northeast, northwest, south, southeast, east, west, and southwest) and with varying distances (0-10 km, 10-20 km, and 20-30 km land distance) from BSWTP. Sampling was carried out between 4 and 14 March, 2023, during a catastrophic fire event at BSWTP. The weather was hot, and no rainfall was observed during the sample collection period. The samples were collected by sweeping the objects containing dust with a plastic-type brush from each household. The collected dust sample was further covered in aluminium foil and was immediately transported to the laboratory and stored at 4°C. After sampling from each site, the sampling brush was washed with acetone to prevent contamination.

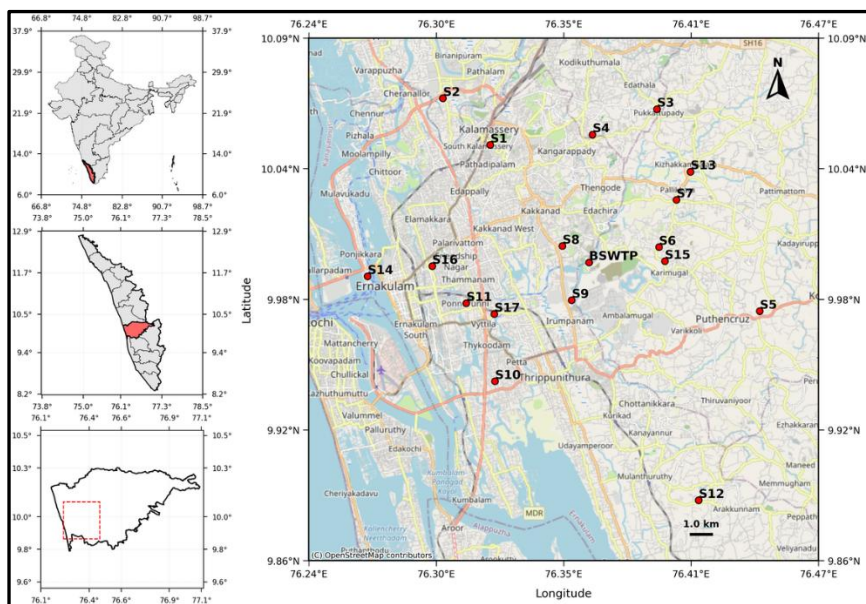
### **2.2 Sample preparation and analysis**

The samples were air dried in a hot air oven at a temperature of 30°C for 2-3 hours and were sieved using a sieve having a mesh size of 63 µm. About 0.1 g of each sieved dust was weighed and transferred to a 250 ml beaker. 10 ml of ultrapure nitric acid (Sigma-Aldrich HNO<sub>3</sub> 70% purified by redistillation) was added, followed by the addition of ultrapure water till it reached the 100 ml mark. Hot plate digestion with a temperature of 95°C was performed on the prepared solution till the solution reached the 50 – 60 ml mark. Further, 2-3 drops of 30% H<sub>2</sub>O<sub>2</sub> were added. The beaker containing the solution was covered with aluminium foil (holes were made in the foil for vapour escape) and was kept aside to attain room temperature.

This cooled solution was filtered twice, beginning with Whatman filter paper No. 1 (pore size 11  $\mu\text{m}$ ), followed by membrane filtration (pore size 0.2  $\mu\text{m}$ ). The filtered solution was stored in a small Teflon bottle until it was subjected to ICP-MS analysis (Thermoscientific iCAP-Q ICP-MS).

### 2.3 Pollution Indices

In order to determine the level of contamination, various pollution indices were introduced. Two such types of pollution indices, such as Contamination Factor (CF) and Geo-accumulation index (Igeo), were computed in this study to determine the level of pollution in the collected household dusts.



**Fig. 1.** Study area depicting the BSWTP and sampling points surrounding BSWTP

#### 2.3.1 Contamination factor (CF)

The contamination factor was computed for dust samples from various household using equation (1) [1].

$$CF = C_n/B_n \quad (1)$$

Where CF = Contamination factor

$C_n$  = concentration of heavy metal 'n' in a particular indoor microenvironment

$B_n$  = Indian natural soil background concentration of heavy metal 'n' (except Cd)

$B_n$  values for various heavy metals are 32015  $\mu\text{g/g}$  for Fe, 56.5  $\mu\text{g/g}$  for Cu, 209  $\mu\text{g/g}$  for Mn, 22.1  $\mu\text{g/g}$  for Zn, 27.7  $\mu\text{g/g}$  for Ni, 13.1  $\mu\text{g/g}$  for Pb, 114  $\mu\text{g/g}$  for Cr .

For Cd, 6  $\mu\text{g/g}$  was taken as the background concentration due to unavailability of data (maximum limit for Cd in Indian soils)

The classification of contamination factors according to pollution is shown in Table 1

**Table 1.** Contamination factor classification [1]

Range	Level of contamination
CF < 1	Low contamination
1 < CF < 3	Moderate contamination
3 < CF < 6	Considerable contamination
CF > 6	Very high contamination

### 2.3.2 Pollution Load Index (PLI)

Pollution load index was used for finding the overall contamination caused by heavy metals in the individual households. The equation (2) was utilised for finding the pollution index. The description of PLI values are shown in Table 2.

$$PLI = (CF_1 * CF_2 * CF_3 * \dots * CF_n)^{1/n} \quad (2)$$

Where,

CF<sub>1</sub> = Contamination factor of site 1

CF<sub>2</sub> = Contamination factor of site 2

CF<sub>3</sub> = Contamination factor of site 3

CF<sub>n</sub> = Contamination factor of site n

**Table 2.** Pollution load index [1].

PLI values	Description
PLI < 1	No overall pollution
PLI > 1	Site contamination

### 2.4 Human health risk assessment

Human health risk assessment was computed based on non-carcinogenic risk and carcinogenic risk [2]. In terms of non-carcinogenic risk, exposure to the studied heavy metals occurs through three main pathways, namely inhalation, ingestion, and dermal exposure. Average Daily Dose (ADD) for each exposure pathway was computed, followed by computation of Hazard Quotient (HQ) for the three exposure pathways. The Hazard Index (HI) was finally derived from the calculated HQs from the three exposure pathways. Separate values were assigned for exposure assessment for children and adults in terms of ADDs, HQs, and HIs. The ADD for inhalation, ingestion, and dermal exposure was calculated from the following equations (3), (4), and (5).

$$ADD_{inh} = (C * InhR * EF * ED) / (PEF * BW * AT) \quad (3)$$

$$ADD_{ing} = (C * IngR * CoF * EF * ED) / (BW * AT) \quad (4)$$

$$ADD_{\text{dermal}} = (C * SA * CoF * AF * ABF * EF * ED) / (BW * AT) \quad (5)$$

Where,

$ADD_{\text{inh}}$  = Average daily dose for inhalation exposure

$ADD_{\text{ing}}$  = Average daily dose for ingestion exposure

$ADD_{\text{der}}$  = Average daily dose for dermal exposure

The values for the variables in equation (3), (4) and (5) are shown in Table 3

**Table 3.** Parameters regarding non-carcinogenic and carcinogenic human health risk assessment [2].

Factor	Definition	Unit	Value (Adult)	Value (Children)
C	Concentration of heavy metals in indoor dusts	mg/kg	-	
InhR	Inhalation rate	m <sup>3</sup> /kg	12.8	7.63
PEF	Particle emission factor	m <sup>3</sup> /kg	1.36 * 10 <sup>9</sup>	1.36 * 10 <sup>9</sup>
IngR	Ingestion rate	mg/day	200	100
EF	Exposure frequency	days/year	365	365
ED	Exposure duration	years	24	6
BW	Body weight	kg	55.9	15
AT	Average time	days	365 * ED	365 * ED
CoF	Conversion factor	kg/mg	1 * 10 <sup>-6</sup>	1 * 10 <sup>-6</sup>
ABF	Dermal absorption factor	-	0.001	0.001
SA	Surface area of skin that contacts dust	cm <sup>2</sup>	4350	1600
AF	Skin adherence factor	mg/cm <sup>2</sup>	0.7	0.2

Hazard Quotient for inhalation, ingestion, and dermal exposure was calculated from the equations (6), (7), and (8). If  $HQ \leq 1$ , there are no harmful health effects, and if  $HQ > 1$ , there are certain health effects [2].

$$HQ_{\text{inh}} = ADD_{\text{inh}} / (RfD_{\text{inh-n}}) \quad (6)$$

$$HQ_{\text{ing}} = ADD_{\text{ing}} / (RfD_{\text{ing-n}}) \quad (7)$$

$$HQ_{\text{der}} = ADD_{\text{der}} / (RfD_{\text{der-n}}) \quad (8)$$

$RfD_{\text{inh-n/ing-n/der-n}}$  = Reference dose of the designated heavy metal 'n'. RfD is an acceptable limit for human hazard assigned for certain metals during regular exposure. RfD values assigned for inhalation, ingestion, and dermal exposure of various heavy metals are shown in the Table 4.

Hazard Index was calculated from the equation (9)

$$HI = \sum HQ_i \quad (9)$$

i = route of exposure (inhalation, ingestion and dermal exposure)

If  $HI < 1$ , there is no non-carcinogenic risk for humans, and if  $HI > 1$ , there is a certain human non-carcinogenic risk.

For carcinogenic risk assessment, Lifetime Average Daily Dose (LADD) for inhalation, ingestion, and dermal exposure was computed, followed by computation of Carcinogenic Risk (CR) for the three routes of exposure. From CR, Total Carcinogenic Risk (TCR) was finally estimated [2]. Out of the metals estimated in this study, only Cu, Cd, Pb, Ni, and Cr are considered carcinogenic elements, and out of these elements, the computation of CR of Cd, Cr, Pb, and Ni was only estimated due to the unavailability of the slope factor for other elements. Out of Cd, Cr, Pb, and Ni, the element Cd was the only one subjected to CR of all routes of exposure due to the availability of data in all three exposure routes, and the rest of the elements were subjected to  $CR_{inh}$  only.

**Table 4.** Reference dose values for the studied heavy metals

Element	RfD <sub>inh</sub>	RfD <sub>ing</sub>	RfD <sub>der</sub>
Pb	$3.52 * 10^{-3}$	$3.5 * 10^{-3}$	$5.25 * 10^{-4}$
Cd	$1 * 10^{-3}$	$1 * 10^{-3}$	$1 * 10^{-5}$
Cr	$2.86 * 10^{-5}$	$3 * 10^{-3}$	$6 * 10^{-5}$
Mn	$1.43 * 10^{-5}$	$4.60 * 10^{-2}$	$1.84 * 10^{-3}$
Ni	$2.06 * 10^{-2}$	$2 * 10^{-2}$	$5.4 * 10^{-3}$
Fe	$8 * 10^{-1}$	$7 * 10^{-1}$	$7 * 10^{-1}$
Zn	$3 * 10^{-1}$	$3 * 10^{-1}$	$6 * 10^{-2}$
Cu	$4.02 * 10^{-2}$	$4 * 10^{-2}$	$1.20 * 10^{-2}$

LADD for three routes of exposure was calculated from the equations (10), (11) and (12)

$$LADD_{inh} = (((C * EF) / (AT * PEF)) * (((InhR_{child} * ED_{child}) / BW_{child}) + ((InhR_{adult} * ED_{adult}) / BW_{adult}))) \quad (10)$$

$$LADD_{ing} = (((C * EF) / AT) * (((IngR_{child} * ED_{child}) / BW_{child}) + ((IngR_{adult} * ED_{adult}) / BW_{adult})) * 10^{-6}) \quad (11)$$

$$LADD_{der} = (((C * EF * ABF) / AT) * (((AF_{child} * SA_{child} * ED_{child}) / BW_{child}) + ((AF_{adult} * SA_{adult} * ED_{adult}) / BW_{adult})) * 10^{-6}) \quad (12)$$

From LADDs, CR for three routes of exposure was calculated from the equations (13), (14) and (15)

$$CR_{inh} = LADD_{inh} * SF_{inh} \quad (13)$$

$$CR_{ing} = LADD_{ing} * SF_{ing} \quad (14)$$

$$CR_{der} = LADD_{der} * SF_{der} \quad (15)$$

Where  $LADD_{inh}$ ,  $LADD_{ing}$ , and  $LADD_{der}$  stand for lifetime average daily doses for inhalation, ingestion, and dermal exposure, while  $CR_{inh}$ ,  $CR_{ing}$ , and  $CR_{der}$  stand for

carcinogenic risks for inhalation, ingestion, and dermal exposure.  $SF_{inh}$ ,  $SF_{ing}$ ,  $SF_{der}$  implies slope factor for inhalation, ingestion, and dermal exposure, which varies with the element being calculated. The values for SF regarding various routes of exposure for various elements are provided in Table 5.

From the equations (13), (14) and (15), TCR was calculated (for Cd only) as shown in equation (16)

$$TCR = \sum CR_i \quad (16)$$

**Table 5.** Slope factor values for various elements in various modes of exposure [2]

Slope factor	Cr	Cd	Ni	Pb
$SF_{inh}$	42	6.30	0.84	0.0085
$SF_{ing}$	-	6.10	-	-
$SF_{der}$	-	6.10	-	-

Where  $i$  = route of exposure (inhalation, ingestion, and dermal exposure).

It is assumed that if  $CR/TCR < 1 * 10^{-6}$ , it is regarded as ‘appreciable,’ and if  $CR/TCR$  values fall between  $1 * 10^{-6}$  and  $1 * 10^{-4}$ , it is regarded as ‘acceptable or tolerable risk.’ If  $CR/TCR$  values exceed  $1 * 10^{-4}$ , then it is assumed that 1 in 10,000 people may develop any type of cancer from lifetime exposure to carcinogenic hazards [2].

## 3 Results and Discussions

### 3.1 Heavy metal concentration in indoor dust

The results of the analysed dust revealed that the total concentration of heavy metals (mg/kg) from various sites followed the pattern:  $S_4 (5214.29) > S_8 (3254.44) > S_9 (2875.30) > S_{13} (2761.90) > S_6 (2729.71) > S_5 (2460.98) > S_2 (2274.37) > S_3 (2273.01) > S_7 (1984.76) > S_{16} (1834.37) > S_1 (1583) > S_{11} (1486.89) > S_{15} (1467.93) > S_{12} (866.47) > S_{14} (446.33) > S_{10} (418.42) > S_{17} (328.99)$ , and in terms of concentration of heavy metals (mg/kg) from the entire sites, it followed the pattern:  $Fe (14905.68) > Mn (377.57) > Cu (275) > Zn (219.41) > Cr (145.91) > Pb (124.86) > Ni (68.89) > Cd (5.58)$ . This pattern of heavy metal concentration was almost the same as the pattern of heavy metals observed in household dusts in urban sites from a previous study, which had Zn, Pb, Cr, and Cu with high concentrations [2].

The present study identified Fe as the heavy metal with the highest concentration and Cd the lowest. Numerous studies conducted worldwide previously have found cadmium as the lowest among all the heavy metals studied. But Fe has not been frequently studied in indoor dust; therefore, comparison of the obtained concentration with previous studies was not possible. A study carried out on indoor air ( $PM_{10}$  and  $PM_{2.5}$ ) of urban and rural households of Agra, India, reported Fe concentration, in which Fe was the highest observed concentration in households situated in both urban and rural sites. Crustal sources and burning of scrap and mixed wastes are identified to be the possible sources of these metals, in which crustal sources like soil and road dust due to resuspension by vehicular movement reach indoor microenvironments through outdoor infiltration. Combustion byproducts from scrap and mixed waste burning also reach the indoor spaces in a similar way.

The concentration of iron in indoor sources is multiple. Iron contamination in indoor dust is mostly observed in houses situated near industries and where smelting operations are active. The households in the present study were closer to industries, and numerous other outdoor (traffic emissions) and indoor sources (wear and tear of furniture, Fe-containing paints and varnishes) might have contributed to this trend. In the case of Cd, the concentration obtained in the present study (5.58 mg/kg) was almost similar to the previous studies. Cd contamination in household dust is influenced mainly by exterior sources related to traffic and atmospheric deposition.

### 3.2 Pollution indices

The contamination factor was computed for various individual elements from various sites and mean CF values of individual metals showed the pattern: Zn > Pb > Cu > Ni > Mn > Cr > Cd > Fe. [2] have studied the contamination factor for heavy metals in dusts (Zn > Cu > Pb > Cr > Cd > Ni), suggesting a pattern similar to this study, with Zn and Pb possessing a high level of contamination compared to other metals. So from the mean CF value for the individual metal, it can be concluded that the Zn and Pb belonged to 'very high contamination' category. Cu belonged to 'considerable contamination' category. Mn, Cr and Ni belonged to 'moderate contamination' category while Fe and Cd belonged to 'low contamination' category.

In case of Pollution load index, except S14 and S17, all sites showed PLI > 1 which implied that 15 out of the 17 sampling sites were contaminated. The order of PLI for various sampling sites showed the pattern: S13 > S16 > S11 > S15 > S9 > S6 > S1 > S5 > S2 > S3 > S12 > S4 > S8 > S7 > S10 > S17 > S14.

### 3.3 Human health risk assessment

Heavy metals are common constituents of aerosols, and prolonged exposure to these metals affects the internal organs of the human body, such as the liver, kidney, lungs, heart, and brain [3]. The exposure takes place mainly in three forms: inhalation, ingestion, and dermal exposure, by which each heavy metal has its own effect on the human body in terms of chronic exposure. The carcinogenic and non-carcinogenic risk assessments were computed in order to check the short-term human health effects of the population residing in the sampling sites.

#### 3.3.1 Non-Carcinogenic human health risk assessment

The results of the computed hazard quotient for three routes of exposure (children and adults) and overall hazard index (children and adults) revealed that the exposed population residing in the households at varying distances away from the landfill are less prone to short-term health effects from the studied metals. The HI for children in the studied sites possessed the pattern: S5 (0.29) > S13 (0.19) > S16 (0.17) > S11 (0.15) > S6 (0.11) > S15 & S9 (0.10) > S17 (0.09) > S2 & S1 (0.07) > S3 & S4 (0.06) > S8 & S12 (0.05) > S7 & S10 (0.04) > S14 (0.03). In the case of adults, HI followed the pattern: S5 (0.25) > S13 (0.16) > S16 (0.13) > S11 (0.11) > S9 & S6 (0.09) > S15 (0.08) > S17 & S4 (0.07) > S2, S1 & S3 (0.06) > S8 (0.05) > S7 & S12 (0.04) > S10 & S14 (0.03). [2] in his study showed HI < 1, similar to the present study, indicating a normal pattern of heavy metal exposure risk, which further states that there has been no new pattern developed on non-carcinogenic risk. The values of HQ<sub>inh</sub>, HQ<sub>ing</sub>, and HQ<sub>der</sub> for both children and adults are shown in Table 6. Out of the studied pathways of exposure, it concluded that exposure through ingestion was predominant,

followed by dermal exposure and inhalation (ingestion > dermal > inhalation) for both children and adults.

**Table 6.** Values of non-carcinogenic health risk parameters of various heavy metals

HQ	HQ <sub>inh</sub> (children)	HQ <sub>inh</sub> (adult)	HQ <sub>ing</sub> (children)	HQ <sub>ing</sub> (adult)	HQ <sub>der</sub> (children)	HQ <sub>der</sub> (adult)
Mn	0.0099	0.0044	0.0547	0.0294	0.0044	0.0112
Cu	2.56E-06	1.15E-06	0.0458	0.0246	0.0005	0.0012
Cr	0.0019	0.0009	0.3242	0.1740	0.0519	0.1325
Fe	6.97E-06	3.14E-06	0.0005	0.0762	0.0005	0.0012
Cd	2.09E-06	9.40E-07	0.0372	0.0200	0.0119	0.0304
Zn	2.74E-07	1.23E-07	0.0049	0.0026	7.80E-05	0.0002
Ni	1.25E-06	5.63E-07	0.0018	0.0123	0.0003	0.0007
Pb	1.33E-05	5.97E-06	0.2378	0.1276	0.0051	0.0130

### 3.3.2 Carcinogenic human health risk assessment

Elements such as Cr, Cd, Ni, and Pb were computed for carcinogenic risk assessment, and only the results of Cd provided details regarding CR for all three routes of exposure and the final computation of TCR. The results of the calculated CR (inhalation, ingestion, and dermal exposures) and TCR are provided in Table 7. From Table 7, it is understood that CR<sub>inh</sub> of Cr, Cd, Ni, and Pb, as well as CR<sub>der</sub> of Cd, fell in the ‘appreciable’ category, while CR<sub>ing</sub> and TCR of Cd fell in the ‘acceptable or tolerable’ category.

A limited number of studies were only analysed for the carcinogenic effect of heavy metals on humans, in which one study in Chengdu, China [2] showed a category similar to the present study. So the present study concludes that households nearby and away from the landfill have no role in short-term carcinogenic risk to the population residing there.

**Table 7.** Exposure route values for CR and TCR for heavy metals from the studied sites

Elements	CR <sub>inh</sub>	CR <sub>ing</sub>	CR <sub>der</sub>	TCR
Cr	5.50E-07	-	-	-
Cd	3.16E-09	6.12E-05	6.98E-07	6.19E-05
Ni	5.20E-09	-	-	-
Pb	9.53E-11	-	-	-

## 4 Conclusion

In order to study the contamination of heavy metals in indoor microenvironments located at varying distances and directions away from the landfill, eight heavy metals, namely Fe, Pb, Cr, Zn, Cu, Mn, Ni, and Cd, were selected based on the elements likely present in waste materials. The results revealed that the concentration of Fe was predominant in the entire sampling location, followed by Mn, Cu, Zn, Cr, Pb, Ni, and Cd. The pollution indices, such

as contamination factor and pollution load index, were monitored in order to assess the contamination in the investigated sites and identified 15 sites as contaminated with Zn and Pb as the most contaminated metals. Since Zn and Pb in the study possessed more contamination compared to other elements, and also from the data observed from the previous study, this study could conclude that Zn and Pb could be used as effective markers. Non-carcinogenic and carcinogenic human health risk assessments made on children and adults revealed that the human population in the studied indoor microenvironments was safe and possessed no immediate toxic or harmful effects to the exposed population amidst the fire event. This study further reveals the usage and credibility of pollution indices as well as human health risk assessment for contamination monitoring at a particular site, which can be used in the future for monitoring site-specific contamination as a routine check or during the occurrence of any unexpected events at specific sites.

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