Unsaturated Zone Leaching Model-driven Probabilistic Human Health Risk Assessment of Groundwater System in the vicinity of Chandigarh Dumping Site, India

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Abstract

The human health risk assessment (HHRA) of groundwater system in the vicinity of Chandigarh dumping site was conducted, assuming oral ingestion and dermal contact exposure scenarios. Observed data of lead (Pb) concentration in the leachate was used to compute cancer risk (CR) by integrating unsaturated 1-D leaching model with probabilistic HHRA framework. The 99 percentile and maximum value of lead (Pb) concentration at the water table was estimated as 0.089 mg/L and 0.506 mg/L, respectively, for pre-monsoon season, higher than the safe limit of 0.050 mg/L. In contrast, for the post-monsoon season, only the maximum value of Pb concentration exceeded the safe limit. Results from 10,000 Monte Carlo simulations showed that the 99 percentile and maximum value of CR for all the sub-populations during pre-monsoon exceeded the safe limit (>10) via oral ingestion exposure to Pb-contaminated groundwater. The 95 percentile value of CR for adult sub-population was estimated as 1.05 x 10 for premonsoon; however, for the post-monsoon season, only maximum values of CR exceeded the safe limit. The cancer risk estimates for the pre-monsoon and post-monsoon seasons via skin dermal contact exposure were found to be lower than the safe level, posing no danger to human health. Among sub-populations, the order of posing CR was found to be in the order as adults (>18 years) > child I (1-5 years) > teen (11-18 years) > child II (6-10 years). Uncertainty analysis showed that the lead concentration (>95% variance contribution), as a major contributor towards uncertainty in the risk estimates, while event duration (t), exposure duration (ED), and ingestion rate (IR) were observed as minor contributors. The approach presented in this study considered the uncertainty in the unsaturated leaching model parameters along with uncertainty in the exposure model parameters, thus can help decision-makers in estimating risk from open dumping sites with minimal data availability.

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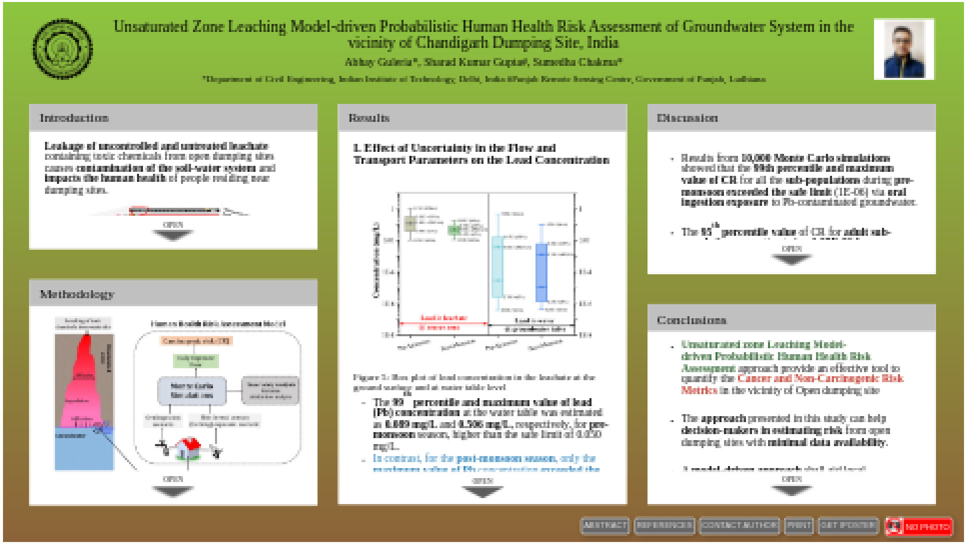

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INTRODUCTION

Leakage of uncontrolled and untreated leachate containing toxic chemicals from open dumping sites causes **contamination of the soil-water system** and **impacts the human health** of people residing near dumping sites.

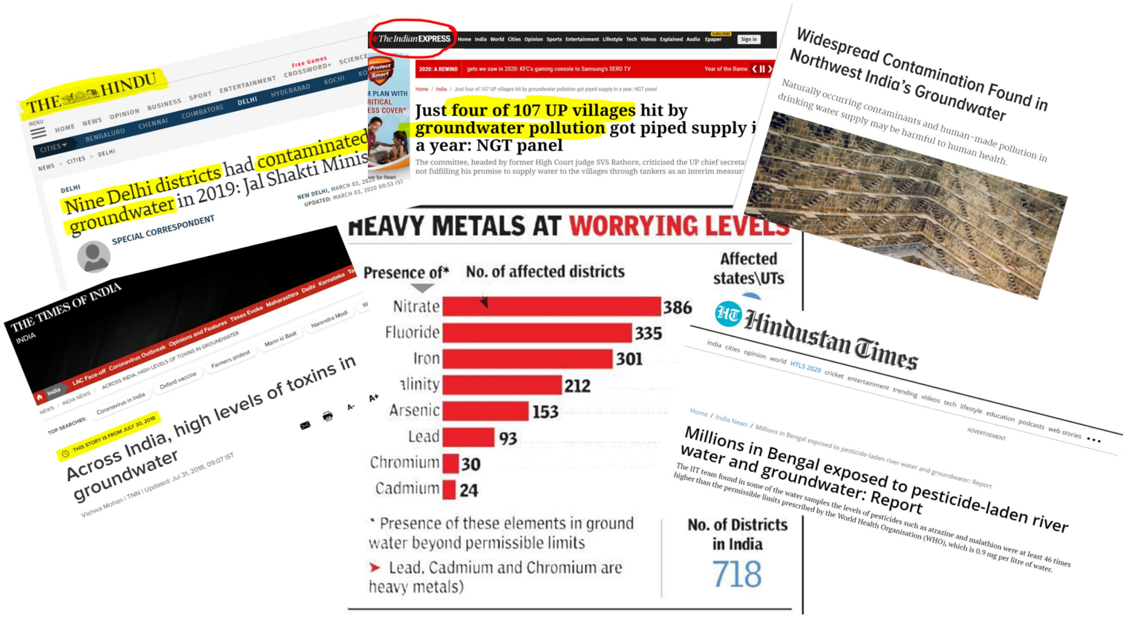


Figure 1: Studies highlighting the groundwater contamination in India (*reported in local and national newspapers*)

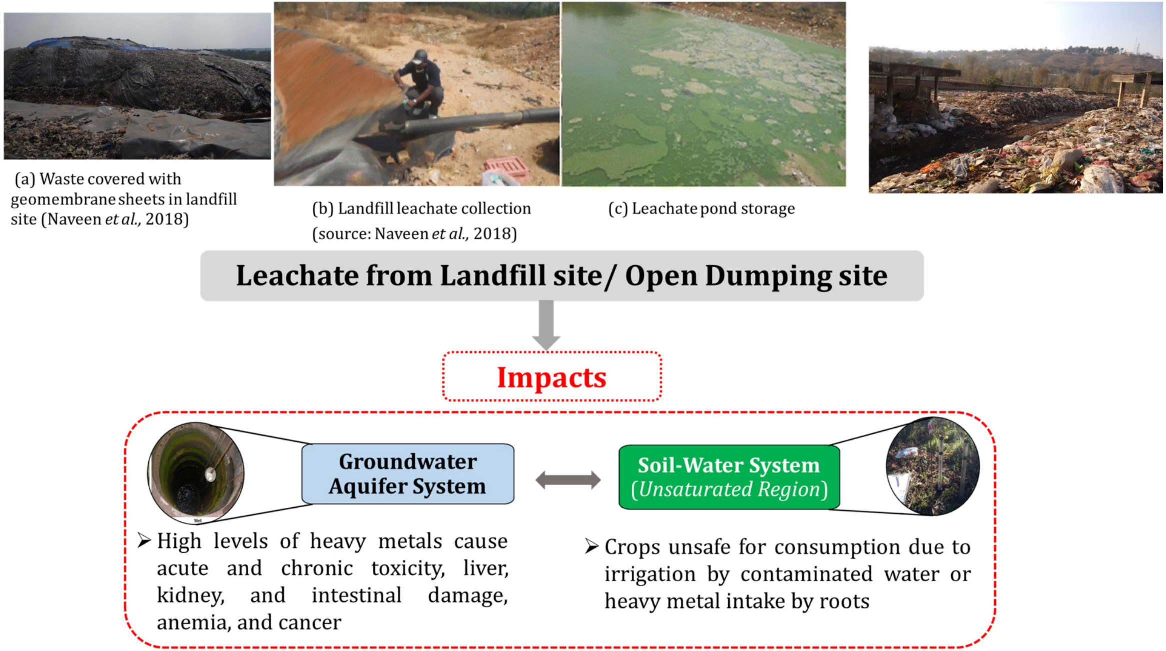


Figure 2: Impacts of leaking of leachate from landfill site or open dumping site

Conventional Risk Assessment Approach

- **Point fixed value** of **exposure model parameters** such as body weight (BW), ingestion rate (IR), exposure frequency (EF), exposure duration (ED), event duration (t_{event}), skin surface area (SA), etc. assumed generally.

- Risk assessment is limited to child and adult sub-population age groups.

- Risk metrics were computed based on the observed concentration data collected from observation points and **neglected** the **effect of flow and transport processes** on contaminant concentration and its associated risk metrics.

Contaminant Transport Model-driven Probabilistic Risk Assessment Approach

The present study considered the following assumptions based on published literature (USEPA, 2001; Troldborg *et al*., 2009; Henri *et al*., 2015; Locatelli *et al*., 2019; Guleria and Chakma 2021a,b):

- Uncertainty in the contaminant source concentration (C_{lead} in the leachate)
  Data source:- Mor *et al*., (2018)
- Uncertainty in flow and transport parameters infiltration rate, decay rate, water content, longitudinal dispersivity (*vertical direction*)
- 4 population groups (Child I, Child II, Teen, Adult)
- A Probabilistic approach for USEPA-based exposure model parameters (BW, IR, SA, EF, ED, event duration, FA, IR_{soil}).

METHODOLOGY

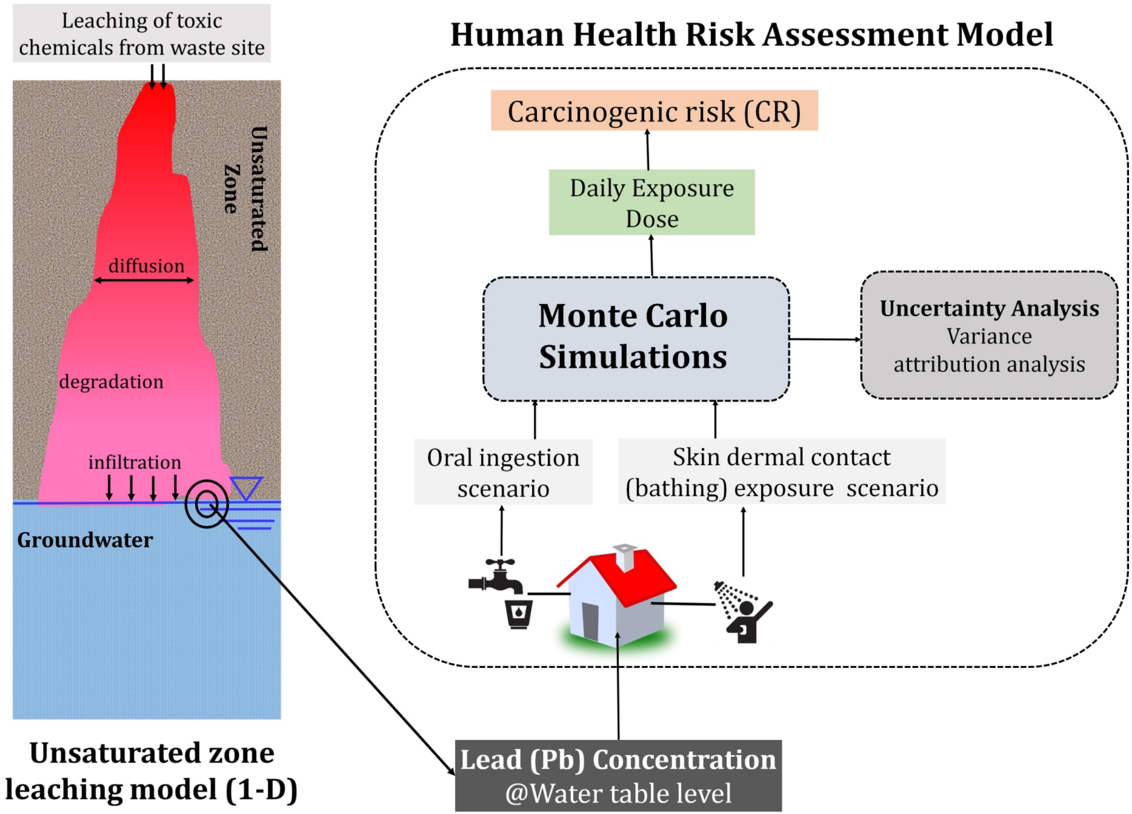
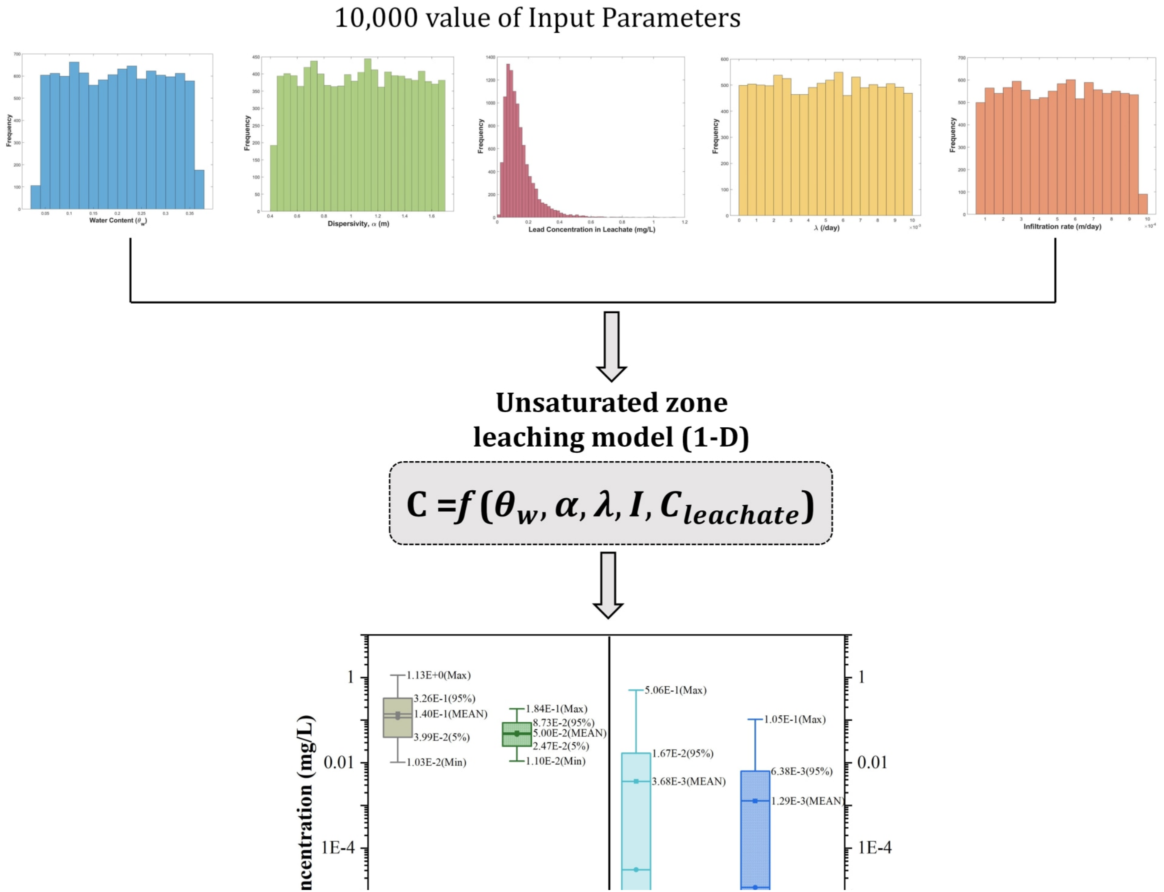


Figure 3: Schematic of Methodology adopted



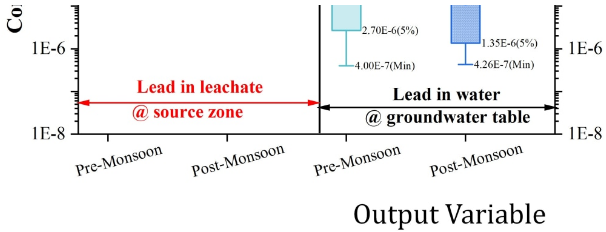


Figure 4: Schematic of Probabilistic Framework of Unsaturated zone Leaching Model

(a) Governing equations of Unsaturated zone leaching model and Human health risk assessment model

The method implemented for the computation of risk metrics is shown in the figure below (USEPA, 2001; Troldborg *et al.*, 2009; Locatelli *et al.*, 2019; Guleria and Chakma 2021a,b).

(b) Input parameters of contaminant transport model

Input parameters such as porosity, soil type, depth to water table from the ground surface, leachate concentration were taken from published literature (Sidhu and Sharma, 1990; CGWB, 2013; Mor *et al.*, 2018; CGWB, 2021).

1-D steady state solution with infinite contaminant source at the land surface (Troldberg *et al.* 2009, Locatelli *et al.* 2019)

$$C_w(z) = C_0 \exp\left(\frac{(v_w - u)z}{2D_z}\right) \text{ ; Where } u = v_w\left(1 + \frac{4\lambda D_z}{{v_w}^2}\right)^{\frac{1}{2}}$$

$$D_z = \frac{(\theta_w D_w^e + \theta_w \alpha_L v_w + \theta_a K_H D_a^e)}{\theta_w}$$

Input Parameters

Chandigarh dumping site

- H – 8.5 m (depth from ground surface to water table)
- Infiltration rate - Uniform distribution (0.02, 0.35 (m/year))
- Porosity (η) - 0.366 (Sandy loam)
- Water content (θ_w) - Uniform distribution ($10\%\ of\ \eta, 100\%\ of\ \eta$)
- Air content (θ_a) - $\eta - \theta_w$
- Diffusion Coe. of lead (Pb) in water $D_w (9.45 \times 10^{-10} m^2/s)$
- 1st order degradation Coe. ($\lambda, /day$) – Uniform (0, 0.01)
- Dispersivity – Uniform $\left(\frac{1}{2} \times \frac{H}{10}, 2 \times \frac{H}{10}\right)$

Human Health Risk Assessment Model

$$ADD_i(GW) = \frac{C_i \times IR \times EF \times ED}{BW \times AT}$$

$$DAD_i(GW) = \frac{DA_{event_i} \times SA \times EV \times EF \times ED}{BW \times AT}$$

$$DA_{event_i} = k_{p_i} \times C_i \times \frac{t_{event}}{1000} \text{ in } \left(\frac{mg}{cm^2 - event}\right)$$

$$CR_{oral} = ADD_i \times CSF_i$$
$$CR_{dermal} = DAD_i \times CSF_i$$

- $CR \geq 10^{-6} \rightarrow$ Potential risk
- $CR < 10^{-6} \rightarrow$ No risk

Lead (Pb) specific input parameters of HHRA

K_p (cm/hour) = 1.0E-04

CSF_O (mg/kg−day)$^{-1}$ = 8.5E − 03

CSF_{ABS} (mg/kg−day)$^{-1}$ = 8.5E − 03

Variance Attribution Analysis

Variance attribution analysis

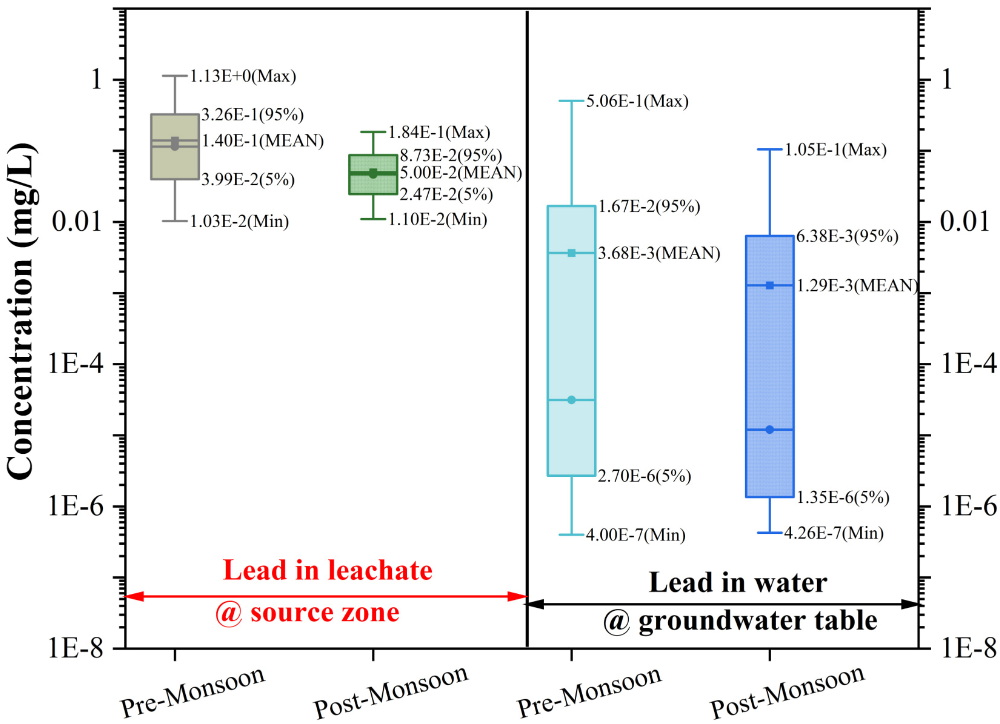
$$Var(HQ) = \sum_{i=1}^{n}\left[Var(A)\left(\frac{dHQ}{dA}\right)^{2}_{\substack{at\ average\\ value}}\right]$$

$$\Rightarrow$$

$$f_A = \frac{Var(A)\left(\frac{dHQ}{dA}\right)^{2}_{\substack{at\ average\\ value}}}{\sum_{i=1}^{n}\left[Var(A)\left(\frac{dHQ}{dA}\right)^{2}_{\substack{at\ average\\ value}}\right]}$$

RESULTS

I. Effect of Uncertainty in the Flow and Transport Parameters on the Lead Concentration



Concentration (mg/L)
1
0.01
1E-4
1E-6
1E-8
1.13E+0(Max)
3.26E-1(95%)
1.40E-1(MEAN)
3.99E-2(5%)
1.03E-2(Min)
1.84E-1(Max)
8.73E-2(95%)
5.00E-2(MEAN)
2.47E-2(5%)
1.10E-2(Min)
5.06E-1(Max)
1.67E-2(95%)
3.68E-3(MEAN)
2.70E-6(5%)
4.00E-7(Min)
1.05E-1(Max)
6.38E-3(95%)
1.29E-3(MEAN)
1.35E-6(5%)
4.26E-7(Min)
Lead in leachate
@ source zone
Lead in water
@ groundwater table
Pre-Monsoon
Post-Monsoon
Pre-Monsoon
Post-Monsoon

Figure 5: Box plot of lead concentration in the leachate at the ground surface and at water table level

- The **99th percentile and maximum value of lead (Pb) concentration** at the water table was estimated as **0.089 mg/L** and **0.506 mg/L**, respectively, for **pre-monsoon** season, higher than the safe limit of 0.050 mg/L.
- In contrast, for the **post-monsoon season**, only the **maximum value of Pb** concentration **exceeded the safe limit** of 0.050 mg/L.

II. Statistical Characterization of Cancer Risk due to Lead

(a) Oral Ingestion Exposure Scenario

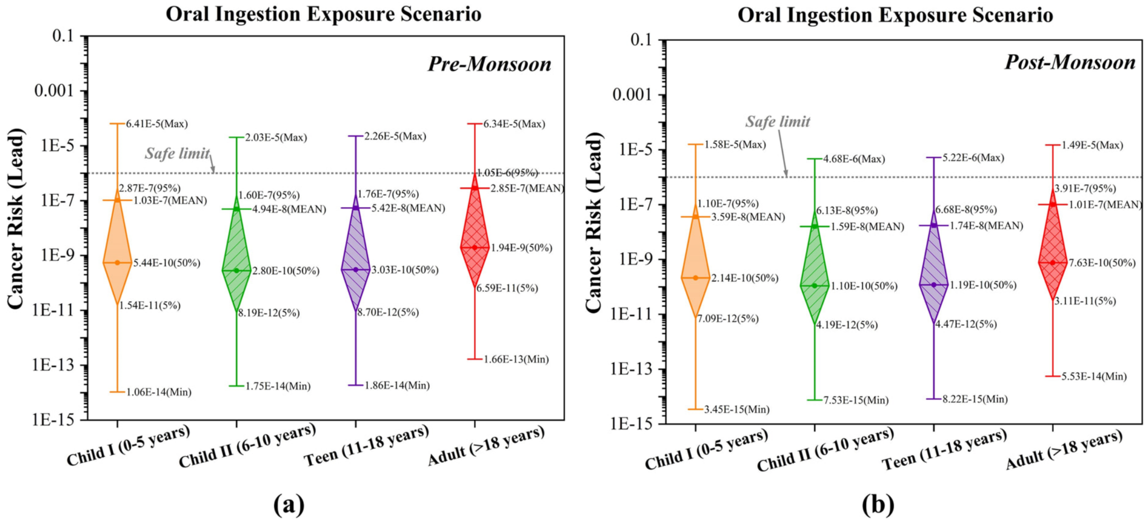


Figure 6: Box plot of cancer risk for oral ingestion scenario during (a) pre-monsoon, and (b) post-monsoon season

(b) Skin Dermal Contact Exposure Scenario

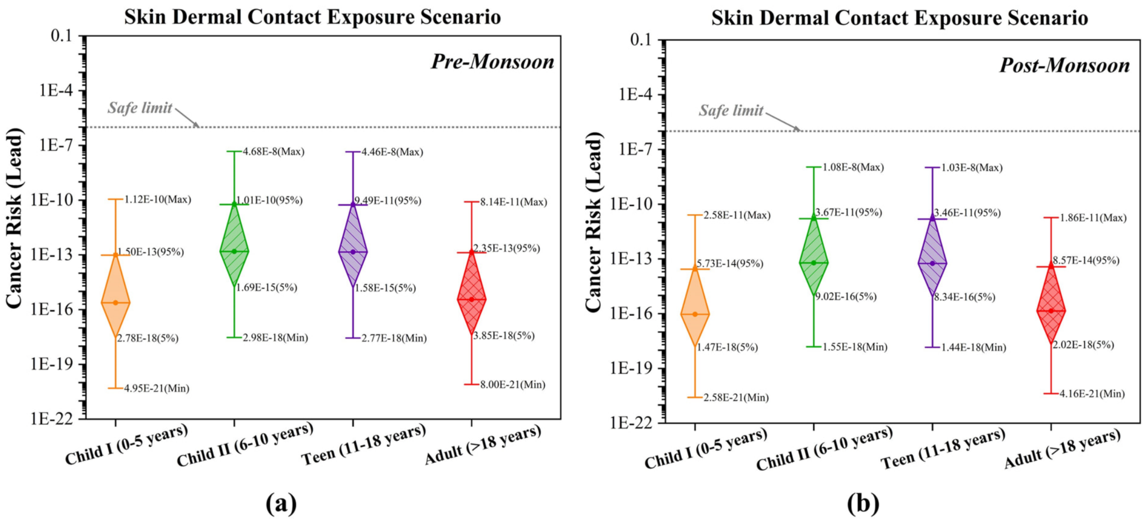


Figure 7: Box plot of cancer risk for skin dermal contact scenario during (a) pre-monsoon, and (b) post-monsoon season

III. Variance Attribution Analysis of Cancer Risk

Variance Attribution Analysis

Exposure Scenario	Contribution Type	Input Parameter	Variance Contribution
Oral Ingestion	Major	Metal concentration (C)	>95%
	Minor	Exposure duration (ED) Ingestion rate (IR)	1% to 2.5% 0.5% to 2.5%
	Minimal effect	Exposure frequency (EF) Body weight (BW)	< 0.20%
Skin Dermal Contact	Major	Metal concentration (C)	88% to 93%
	Minor	Event duration (t_{event}) Exposure duration (ED)	3.5% to 6.5% 2% to 3%
	Minimal effect	Skin surface area (SA) Body weight (BW) Exposure frequency (EF) Fraction of skin surface area (FA)	<0.5%

DISCUSSION

- Results from **10,000 Monte Carlo simulations** showed that the **99th percentile and maximum value of CR** for all the **sub-populations** during **pre-monsoon exceeded the safe limit** (1E-06) via **oral ingestion exposure** to Pb-contaminated groundwater.

- The **95th percentile value** of CR for **adult sub-population** was estimated as **1.05E-06 for pre-monsoon**; however, for the **post-monsoon season**, **only maximum values of CR exceeded the safe limit.**

- The **cancer risk estimates** for the pre-monsoon and post-monsoon seasons via **skin dermal contact exposure** were found to be **lower than the safe level**, posing no danger to human health.

- The overall **ranking order of posing CR**: Adults (>18 years) > child I (1-5 years) > teen (11-18 years) > child II (6-10 years)

- **Uncertainty analysis** showed that the **lead concentration - major contributor** towards uncertainty in the risk estimates.

- Event duration (**tevent**), exposure duration (**ED)**, and ingestion rate (**IR**) - **minor contributors**.

CONCLUSIONS

- **Unsaturated zone Leaching Model-driven Probabilistic Human Health Risk Assessment** approach provide an effective tool to quantify the **Cancer and Non-Carcinogenic Risk Metrics** in the vicinity of Open dumping site

- The **approach** presented in this study can help **decision-makers in estimating risk** from open dumping sites with **minimal data availability**.

- A **model-driven approach** shall aid local governments in **framing groundwater pollution-related policies** and help in the effective management of open dumping sites.

ABSTRACT

Leaching of toxic chemicals from non-engineered and unlined dumping sites causes contamination of the soil-water system and affects the aquifers below the water table. The contamination of groundwater in and around waste dumping sites poses a danger to people's health, such as chronic diseases, digestive disorders. Thus, the human health risk assessment (HHRA) of the groundwater system in the vicinity of the Chandigarh dumping site was conducted, assuming oral ingestion and dermal contact exposure scenarios. Observed data of lead (Pb) concentration in the leachate was used to compute cancer risk (CR) by integrating unsaturated 1-D leaching model with probabilistic HHRA framework. The 99th percentile and maximum value of lead (Pb) concentration at the water table was estimated as 0.089 mg/L and 0.506 mg/L, respectively, for pre-monsoon season, higher than the safe limit of 0.050 mg/L. In contrast, for the post-monsoon season, only the maximum value of Pb concentration exceeded the safe limit. Results from 10,000 Monte Carlo simulations showed that the 99th percentile and maximum value of CR for all the sub-populations during pre-monsoon exceeded the safe limit ($>10^{-6}$) via oral ingestion exposure to Pb-contaminated groundwater. The 95th percentile value of CR for adult sub-population was estimated as 1.05×10^{-6} for pre-monsoon; however, for the post-monsoon season, only maximum values of CR exceeded the safe limit. The cancer risk estimates for the pre-monsoon and post-monsoon seasons via skin dermal contact exposure were found to be lower than the safe level, posing no danger to human health. Among sub-populations, the order of posing CR was found to be in the order as adults (>18 years) > child I (1-5 years) > teen (11-18 years) > child II (6-10 years). Uncertainty analysis showed that the lead concentration (>95% variance contribution), as a major contributor towards uncertainty in the risk estimates, while event duration (t_{event}), exposure duration (ED), and ingestion rate (IR) were observed as minor contributors. The approach presented in this study can help decision-makers in estimating risk from open dumping sites with minimal data availability. Such a model-driven approach shall aid local governments in framing groundwater pollution-related policies and help in the effective management of open dumping sites.

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