

Uncertainty Quantification of Non- Carcinogenic Soil Risk Assessment of Heavy Metal Contamination Near Oil Refinery Area: A Case Study

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ABSTRACT

Uncertainty is inherent in almost all aspects of our life. We usually ignore uncertainty to avoid complexity. However, solutions so obtained are quite far from the reality and ignoring uncertainty may lead to over (under) estimation. So, we need to quantify the uncertainty so as to be aware of the risk involved in any decision-making process. Uncertainties can be modeled and analyzed using different theories, viz. Probability theory, Possibility theory, Evidence theory etc. Modeling of an uncertain parameter depends on the nature of the information available. This paper considered uncertainty quantification of parameters in the case of risk assessment. Risk means, risk associated with the heavy metal released into the environment. There are various pathways through which the heavy metal can reach human being namely inhalation, ingestion through drinking water and through contaminate food. The main aim of risk assessment is to determine the potential detriment to human health from exposure to a substance or activity that under plausible circumstances can cause to human health. This paper analyzed the propagation of the risk in terms of probability theory. One advanced method of probabilistic risk assessment (PRAs), P-box method is discussed in this paper. A case study is also carried out with this method.

Keywords

Uncertainty, Variability, Probability bounds analysis, Probability-box(p-box).

1. INTRODUCTION

Uncertainty analysis is a systematic study in which “a neighborhood of alternative assumptions is selected and the corresponding interval of inferences is identified” [1]. Uncertainty plays a critical role in the analysis for a wide and diverse set in various fields. Ideals and concepts of uncertainty have long been associated with gambling and games. The Greek in the 4th century BC were the first recorded civilization to have considered uncertainty. There are two kinds of uncertainty. One kind arises as variability (or Aleatory uncertainty) resulting from inherent variability, natural stochasticity, environmental or structural variation across space or through time, manufacturing or genetic heterogeneity among components or individuals, and variety of other sources of randomness. It is also called randomness, Stochastic Uncertainty, Objective Uncertainty, dissonance, or Irreducible Uncertainty. The standard representation of variability is the probability distribution function. The other kind called Epistemic Uncertainty is defined as uncertainty which arises from incompleteness of knowledge about the world. Sources of epistemic Uncertainty include measurement uncertainty, small sample size, detection limits and data censoring, ignorance about the details of the physical mechanisms and processes

involved and other imperfection in scientific understanding.

These two kinds of Uncertainty can propagate through various mathematical expressions with different calculation method. Probability Bounds Analysis (PBA) is related to one of these methods. It is a combination of probability theory and Interval Analysis. Probability Theory is used to propagate Aleatory Uncertainty (or variability) and Interval Analysis is used to propagate Epistemic Uncertainty (or Uncertainty). Probabilistic approaches characterize the uncertainty in the parameter by a probability distribution.

If the uncertainty consists purely of variability, we don't know which particular value will come up in a random selection, but we know how likely each value is. This uncertainty represents by an interval. Interval approach represents with an interval having lower bounds and upper bounds. Probability bounds analysis allows one to obtain fully rigorous results even when the empirical information is very poor. The idea of bounding probability has a very long tradition in probability theory. The uncertainty is characterized by a probability distribution, or by a p-box in the case of the probability bounds approach. P-box arises from probability distribution when there is uncertainty about the values of the defining parameters (mean, standard deviation etc.).

1.1 Exposure Pathways

An exposure pathway is any route that a chemical may travel from an environmental source to a receptor. An exposure pathway has five main parts [5]:

- A chemical source
- A release mechanism (e.g., leaking, leaching, wind erosion)
- A transport and/or exposure medium (e.g., air, water, soil, sediment, food),
- An exposure point with receptors present or potentially present (actual location where exposure is possible), and
- A route of entry (inhalation, ingestion, dermal contact).

A complete exposure pathway is one that has no functional barrier that prevents an exposure. The pathway may be completed (i) by the chemical moving from the source to the receptor or (ii) by the receptor moving to the source. In this case study we used the ingestion path way only.

2. PROBABILITY BOX (P-BOX) METHOD:[2]

If the cumulative distribution functions for some variable lies on or between two monotonic curves, then these curves form a box can be called a probability box or p-box for that variable.

A real-valued random variable is characterized by its distribution function, which is a monotonically increasing function from the real numbers into the interval [0, 1] such that the value of the function at negative infinity is zero and the value of the function at positive infinity is one. A probability box or “p-box” consists of a pair of such functions that are used to circumscribe an imprecisely known distribution function F .

There are two kinds of p-box. One is parametric p-box and other is nonparametric p-box. For parametric models where the distribution is specified, but the parameters of the model are described by intervals. Such type of p-box is called parametric p-box. But some p-box does not need a large amount of information. Such types of p-box can be constructed based on namely minimum, maximum, mean, median, mode, variance, percentile etc. This type of p-box is called nonparametric p-box.

Probability boxes can be used wherever a probability distribution can be used. P-boxes can be freely combined with scalars, interval and probability distribution in mathematical expression. It is not needed whether a variable is precisely specified distribution or only bounds on possibility distribution. Advantages of P-box are that there is a method for combining p-boxes for different random quantities without assuming anything about the dependence between random quantities and they are useful tools for risk analysis.

3. A CASE STUDY ON SOIL RISK OF THE HEAVY METAL CONTAMINATION

The possible adverse effects of non-carcinogenic exposure to heavy metal, this study followed the guidelines for toxicant assessment outlined by the United States Environmental Protection Agency (USEPA). Adverse Daily Intake (ADI) and

Hazard Quotient (HQ) calculations were made using the data shown in Table 1 and 2. The essential parameter, Adverse daily intake (ADI) was computed using the following equation

$$ADI = \frac{C \times IR \times EF \times ED}{BW \times AT} \times 10^{-6} \dots (1)$$

Where, C = concentration of metals

IR = ingestion rate = 100 mg kg⁻¹

EF = Exposure frequency = 350 days/ year

ED = Exposure duration = 30 years

BW = Body weight = 70 kg

AT = Averaging time = ED × 365 = 30 × 365 = 10950 days [USEPA, 2002]

The subsequent equation was utilized for the calculation of the Hazard Quotient (HQ):

$$HQ = \frac{ADI}{RfD} \dots (2)$$

Where RfD is the heavy metal reference dosage mgkg⁻¹/day

To assess the overall non-carcinogenic effects posed by a combination of various chemicals, the Hazard Index (HI) was determined by the summation of individual HQ values. This comprehensive approach helps in evaluating the combined risk of exposure to multiple substances

$$HI = \sum HQ_i = \sum \frac{ADI}{RfD_i} \dots (3)$$

Table 1: Concentration of some heavy elements present in Makum, India coals/lignite(mg/kg):[4]

Heavy Metal	Concentration (mg/kg)	Representation
Mn	[15.27, 63.81]	Probabilistic
Cu	[9.86, 30.35]	Probabilistic
Pb	[5.06, 24.13]	Probabilistic
As	[0.04, 0.24]	Probabilistic

Here, concentration is considered as triangular distribution taking the most likely value as a mean.

Table 2: Reference dosage of heavy elements presents in Makum, India: [7]

Heavy Metal	RfD (mgkg ⁻¹ /day)
Mn	1.4 × 10 ⁻¹
Cu	4.0 × 10 ⁻²
Pb	3.5 × 10 ⁻³
As	3 × 10 ⁻⁴

4. RESULT AND DISCUSSION

Hazard Quotient (HQ) values provide insight into the extent of non-carcinogenic health impacts, with value below 1 indicating no significant impact and values above 1 signifying considerable health concerns. Similarly, when assessing the Hazard Index (HI), an HI value below 1 suggests minimal or negligible risks to non-cancer health, where as an HI values exceeding 1 indicates a substantial risk [6].

This study exclusively concentrated on assessing the non-carcinogenic risk through the ingestion pathways. Table 1 displays the concentration of several heavy metal (Mn,Cu,Pb, and As), each of which has varying effects on both human health and the environment. Table 2 displays the reference dosages of the heavy elements present [3]. Here, Risk_Cal software used to evaluate the Risk.

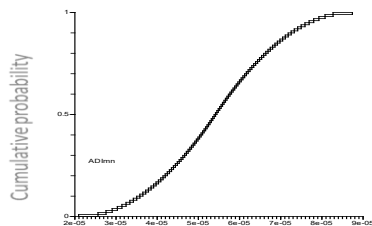


Fig 1 Average daily intake of Mn

range=[2.09178e-05,8.7411e-05],
mean=5.41644e-05

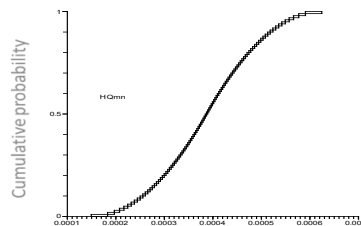


Fig 2 Hazard Quotient of Mn

range=[0.000149413,0.000624364],
mean=0.000386888

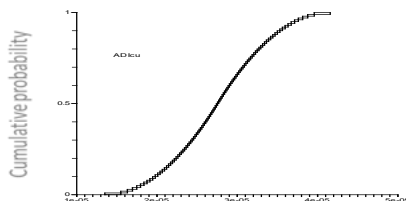


Fig 3 Average daily intake of Cu

range=[1.35068e-05,4.15753e-05]
mean=2.75411e-05

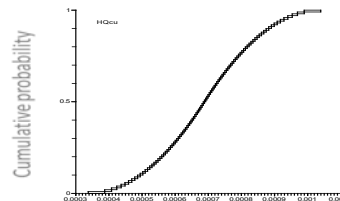


Fig 4 Hazard Quotient of Cu

range=[0.000337671,0.00103938],
mean=0.000688527

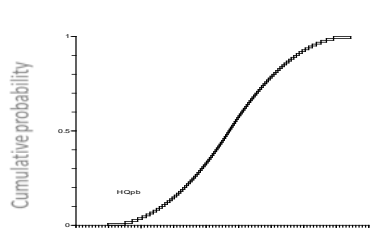


Fig 5 Hazard Quotient of Pb

range=[0.00198043,0.00944423],
mean=0.00571233

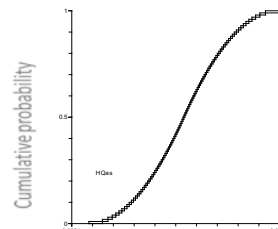


Fig 6 Hazard Quotient of As

range=[0.000182648,0.00109589],
mean=0.000639269,

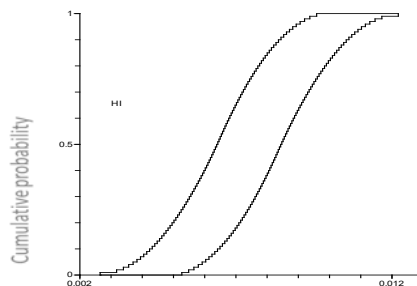


Fig 7 Hazard Index of heavy metal

range=[0.00265016,0.0122039], mean=0.00742701

Here, Fig 1 and Fig 3 shows the average daily dose for the metal Mn and Cu respectively. Fig 2 shows the Hazard Quotient (HQ) for Mn whose range is lying in the interval [0.000149413,0.000624364], which is below 1. Hence by USEPA guideline indicate no significant health impact. Similarly Fig 4, Fig 5 and Fig 6 shows the HQ for the heavy metal Cu, Pb and As. The range of Cu is lying in the interval [0.000337671,0.00103938], which indicating no significant health impact. The ranges of Pb and As are in the interval [0.00198043,0.00944423] and [0.000182648,0.00109589] which are also shows no significant health impact individually.

Fig 7 shows the Hazard Index of heavy metal of Mn,Cu,Pb and As. The range is in the interval [0.00265016,0.0122039], which is also below 1. Hence the final result gives minimal or negligible risks to non-cancer health for containing heavy metal. The findings from this study can be immensely valuable for decision-maker seeking to formulate more effective strategies to reduce exposure and efficiently manage soil pollution.

5. REFERENCES

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