地下水致癌化合物的劃分式多目標風險建模

Lemke, L. D., Bahrou, A. S., 2009. Partitioned multiobjective risk modeling of carcinogenic compounds in groundwater. *Stochastic Environmental Research and Risk Assessment*, **23**, 27–39.

報告者：廖泓硯
指導教授：陳瑞昇 老師
報告日期：2023/12/15

摘要

暴露於受污染地下水對人體癌症的風險量化受到多種水文地質、環境和毒理學不確定性的影響。本研究以四氯乙烯(PCE)為例，使用三個獨立模型進行連接：(1)污染物傳輸模型；(2)人體暴露途徑模型；以及(3)PCE 癌症潛能因子模型。水文地質模型包含了一維移流-延散-反應傳輸方程的解析解，以確定離連續源固定距離的水供應井中的 PCE 濃度。途徑模型則包括通過攝食、吸入和皮膚接觸的 PCE 暴露。毒理學模型則將 PCE 暴露的流行病學數據結合為人類 PCE 癌症潛能因子的複合累積分布頻率曲線。本研究通過在 20,000 次蒙特卡羅模擬中計算的期望癌症風險，評估了各個模型變數的相對重要性。對於所評估的情景，三個與癌症風險最高度相關的因子是：(1)地下水中 PCE 的降解常數，(2)線性地下水孔隙速度，以及(3)癌症潛能因子。然後應用了劃分式多目標風險方法(PMRM)，以增加 1/100,000 的癌症風險作為閾值產生有條件的期望值函數。這種方法可以將低概率/高影響的結果與傳統無條件期望值區分開來，從而可以為決策者量化潛在的最壞情況。使用 PMRM，本研究評估了實施幾種假設的風險管理替代方案的成本效益關係，旨在減輕預期和條件下的癌症風險。結果強調了水文地質模型在風險評估中的重要性，同時也說明了整合環境和毒理學不確定性的重要性。當結合 PMRM 時，集成了傳輸、暴露和潛能的不確定性的模型構成了在風險修正行動(RBCA)框架內使用的有效風險評估工具。

關鍵字： 地下水污染，風險修正行動，隨機分析，不確定性

Stoch Environ Res Risk Assess (2009) 23:27–39
DOI 10.1007/s00477-007-0192-4

ORIGINAL PAPER

Partitioned multiobjective risk modeling of carcinogenic compounds in groundwater

Lawrence D. Lemke · Andrew S. Bahrou

Published online: 17 October 2007
© Springer-Verlag 2007

Abstract Quantifying human cancer risk arising from exposure to contaminated groundwater is complicated by the many hydrogeological, environmental, and toxicological uncertainties involved. In this study, we used Monte Carlo simulation to estimate cancer risk associated with tetrachloroethene (PCE) dissolved in groundwater by linking three separate models for: (1) reactive contaminant transport; (2) human exposure pathways; and (3) the PCE cancer potency factor. The hydrogeologic model incorporates an analytical solution for a one-dimensional advective–dispersive–reactive transport equation to determine the PCE concentration in a water supply well located at a fixed distance from a continuous source. The pathway model incorporates PCE exposure through ingestion, inhalation, and dermal contact. The toxicological model combines epidemiological data from eight rodent bioassays of PCE exposure in the form of a composite cumulative distribution frequency curve for the human PCE cancer potency factor. We assessed the relative importance of individual model variables through their correlation with expected cancer risk calculated in an ensemble of Monte Carlo simulations with 20,000 trials. For the scenarios evaluated, three factors were most highly correlated with cancer risk: (1) the microbiological decay constant for PCE in groundwater, (2) the linear groundwater pore velocity, and (3) the cancer potency factor. We then extended our analysis beyond conventional expected value risk assessment using the partitioned multiobjective risk method (PMRM) to generate expected-value functions conditional to a 1 in 100,000 increased cancer risk threshold. This approach accounts for low probability/high impact outcomes separately from the conventional unconditional expected values. Thus, information on potential worst-case outcomes can be quantified for decision makers. Using PMRM, we evaluated the cost-benefit relationship of implementing several postulated risk management alternatives intended to mitigate the expected and conditional cancer risk. Our results emphasize the importance of hydrogeologic models in risk assessment, but also illustrate the importance of integrating environmental and toxicological uncertainty. When coupled with the PMRM, models integrating uncertainty in transport, exposure, and potency constitute an effective risk assessment tool for use within a risk-based corrective action (RBCA) framework.

Keywords Groundwater · Contamination · Risk-based corrective action · Stochastic analysis · Uncertainty