DNAPL 污染場址之宿命和污染物傳輸模式驅動機率式人體健康風險評估

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摘要

本研究利用位於美國佛羅里達州空軍基地區域地下環境中存在的重質非水相液體（DNAPLs），計算了宿命和污染物傳輸模式驅動的人體健康風險指數。利用 DNAPLs 的汙染源濃度數據，通過 10,000 次蒙地卡羅類型模擬，計算兒童和成人透過直接攝入和皮膚接觸暴露情境的傳輸模式驅動的健康風險指數。基於 50 年的模擬時間跨度，降解的 DNAPL 化合物（順二氯乙烯（cis-DCE），氯乙烯（VC））相比母化合物（四氯乙烯（PCE））的機率分布變化較大。降解的 DNAPL 化合物（VC，cis-DCE）相比母化合物（PCE）對人體健康造成較高風險，也持續較長時間（長達 15 年）。從第 2 年到第 5 年的時間跨度內觀察到的致癌健康風險比安全限值（$HQ_{Safe} < 10^{-6}$）高了 3 個數量級，並處於高風險區，表明需要針對受污染地點制定修復計劃。變異數歸因分析顯示，濃度、體重和暴露時間（貢獻百分比為 70 至 95%）是最重要的參數，突顯了延散度和暴露模型對風險指數估算的影響。本方法可以幫助決策者在評估有部分水文地質特性數據和模型參數不確定性較高的受污染地點時制定整治措施。

關鍵字： 機率式人體健康風險評估、重質非水相液體、地下水、模式驅動風險指數、蒙地卡羅模擬

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RESEARCH ARTICLE

Fate and contaminant transport model-driven probabilistic human health risk assessment of DNAPL-contaminated site

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Abstract
In this study, fate and contaminant transport model-driven human health risk indexes were calculated due to the presence of dense non-aqueous phase liquids (DNAPLs) in the subsurface environment of air force base area in Florida, USA. Source concentration data of DNAPLs was used for the calculation of transport model-driven health risk indexes for the children and adult sub-population via direct oral ingestion and skin dermal contact exposure scenario using 10,000 Monte Carlo type simulations. The highest variation in the probability distribution of transformed DNAPL compound (cis-dichloroethene (cis-DCE) > vinyl chloride (VC)) was observed as compared to parent DNAPL (tetrachloroethene (PCE)) based on the 50-year simulation timespan. Transformed DNAPL compounds (VC, cis-DCE) posed the highest risk to human health for a longer duration (up to 15 years) in comparison to parent DNAPL (PCE), as non-carcinogenic hazard quotient varied from 400 to 1100. Carcinogenic health risks were observed as 3-order of magnitude higher than safe limit ($HQ_{Safe} < 10^{-6}$) from 2nd to 5th year timespan and fall in the high-risk zone, indicating the need for a remediation plan for a contaminated site. Variance attribution analysis revealed that concentration, body weight, and exposure duration (contribution percentage – 70 to 95%) were the most important parameters, highlighting the impact of dispersivity and exposure model in the estimation of risk indexes. This approach can help decision-makers when a contaminated site with partial data on hydrogeological properties and with higher uncertainty in model parameters is to be assessed for the formulation of remediation measures.

Keywords Probabilistic human health risk assessment · DNAPLs · Groundwater · Model-driven risk index · Monte Carlo simulations