An integrated human health risk assessment framework for alkylphenols due to drinking water and edible crop consumption

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INTRODUCTION

The scarcity of clean freshwater is becoming a major issue for present and future generations, especially in densely urbanised areas. This situation promotes the potential cross-contamination of different environmental compartments by contaminants of emerging concern (CECs) which, in fact, have already been detected worldwide in surface water, groundwater and soils. In particular, the CECs released by wastewater treatment plants (WWTPs) can end up both in the recipient surface water and groundwater, both of which are used as drinking water (DW) sources. Furthermore, if those water sources and reclaimed wastewater are used for irrigation, CECs can be directly absorbed by crops intended for human consumption or accumulate in soil and translocate to crops over time. Hence, both DW and edible crops are critical CEC exposure pathways for humans, the combined effect of which requires further investigation. This work is aimed at developing an integrated framework for a quantitative chemical risk assessment due to CECs in complex multiple-use scenarios, combining DW and edible crop consumption, as a decision-making support tool for optimising solutions to minimise risks and social costs.

METHODOLOGY

The developed procedure includes several steps. Firstly, the analysed system boundaries are defined, to evaluate all the phenomena affecting the fate of CECs from source to end user. Then, CEC migration (e.g. diffusion in surface water, infiltration in soil, uptake by food crops) and human exposure (via water and edible crop consumption) are modelled in an integrated framework as a function of boundary conditions, CECs and by-products characteristics, and proposed interventions. Exposure models are calibrated through literature data, field monitoring and lab tests where, for instance, the CECs' fate and uptake by vegetables from contaminated soils have been investigated. In the hazard assessment step, a toxicological characterisation was performed to obtain single CEC adverse effect potencies, aimed at applying the Relative Potency Factors methodology for combining CECs that affect the same endpoint. Lastly, exposure and hazard assessment steps are combined to quantitatively estimate the risk to human health from a mixture of CECs, which includes uncertainty analyses to account for knowledge gaps and to provide decision-makers with the confidence level of the risk estimation.

RESULTS

The developed quantitative risk assessment procedure has been applied to a case study on the mixture of two alkylphenols, i.e. bisphenol-A (BPA) and nonylphenol (NP), used as reference CECs. Literature and field-monitoring data were used to feed the model, with an estimate of BPA and NP concentration in DW up to 0.1 and 0.35 µg/L, respectively, as a function of different system boundary conditions. As for their uptake in edible crops, lab tests with contaminated soil (BPA=75 µg/kg and NP=10 mg/kg, according to the range reported in literature for soil irrigated with reclaimed wastewater or amended with biosolids) demonstrated a significant transfer of NP from soil to vegetables, with concentrations of up to 230 µg/kg fresh weight (f.w.) in the edible parts. No BPA (<8 µg/kg f.w.) was found in vegetables, unlike its metabolite para-hydroxybenzoic acid (up to 56 µg/kg f.w). Those results highlight that both DW and edible crop consumption exposure pathways are critical for the risk to human health due to BPA, NP and their by-products. Several interventions in WWTPs or in DW treatment plants and distribution networks were simulated, demonstrating promising cumulative risk reduction.

DISCUSSION

Integrated modelling of the fate of CEC mixtures in complex multiple-use water systems, combined with quantitative risk assessment, has proven to be an effective tool to identify the main causes of risk for humans and to assign the various CEC source contributions. Lab tests proved to be useful to investigate the fate of CECs, including metabolites, in the soil system and potential transfer to food crops, corroborating the information from literature and monitoring data for model calibration. Integrated modelling also made it possible to explore several intervention strategies to be adopted at different points of the water system, identifying those that achieve the minimum overall mixture risk. Moreover, in addition to CEC toxicological characterisation, this procedure allows decision-makers to prioritise CECs to be regulated not only based on their exposure levels but looking at their contribution to the overall mixture risk. Lastly, uncertainty analysis made it possible to properly consider the availability and quality of CEC data, especially as regards their physical-chemical behaviour and toxicity, thereby providing the degree of confidence for the estimated risk, which is a key factor for taking informed decisions concerning CECs.