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A risk-based methodology for ranking environmental chemical stressors at the regional scale

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ABSTRACT

A "Risk-based Tool for the Regional Ranking of Environmental Chemical Stressors" has been developed, aimed at supporting decision-makers in the identification of priority environmental contaminants, as well as priority areas, to be further assessed. The tool implements a methodology based on a quantitative Weight-of-Evidence approach, integrating three types of information, identified as "Lines-of-Evidence" (LoE), namely: LoE "Environmental Contamination" (including data on chemical contamination in environmental matrices in the region, thus providing information on potential population exposure), LoE "Intake" (including results from human biomonitoring studies, i.e. concentration of chemicals in human biological matrices, thus providing an integrated estimation of exposure) and LoE "Observed Effects" (including information on the incidence of adverse health outcomes associated with environmental exposure to chemicals).

A Multi-Criteria Decision Analysis (MCDA) methodology based on fuzzy logic has been developed to support the integration of information related to these three LoEs for each chemical stressor. The tool allows one to rank chemical stressors at different spatial scales, such as at the regional level as well as within each sub-area (e.g., counties). Moreover, it supports the identification of priority sub-areas within the region, where environmental and health data suggest possible adverse health effects and thus more investigation efforts are needed.

To evaluate the performance of this newly developed tool, a case-study in the Flemish region (north of Belgium) has been selected. In the case-study, data on soil contamination by metals and organic contaminants were integrated with data on exposure and effect biomarkers measured in adolescents within the framework of the human biomonitoring study performed by the Flemish Centre of Expertise on Environment and Health in the period 2002–2006. The case-study demonstrated the performance of the tool in integrating qualitative and quantitative data with expert judgement for the identification of priority contaminants and areas. The proposed approach proved to be flexible, allowing for the incorporation of individual decision-maker's preferences, and, at the same time, to be transparent since all assumptions and value attributions are traceable.

1. Introduction

The debate on the relationships between environmental quality and human health is continuously enlivened by citizens' concerns and new evidence provided by scientific research and is influencing the EU policy agenda on environmental health issues. Even though in the last decades EU environmental legislation was aimed at reducing the negative effects of chemical and physical stressors generated by anthropogenic pressures on ecosystems and human populations, there is still the need for identifying actual, emerging and potential health threats linked to environmental pollution and to propose and implement adequate risk management actions. To promote and enhance an effective plan for better understanding and adequately managing environmental health issues at the European scale, the European Commission developed in 2003 the "Environment and Health Strategy" (EC, 2003), followed by the "Environment and Health Action Plan 2004–2010" (EC, 2004). The Action Plan promotes the improvement of the "environment and health" information chain, the strengthening of research efforts for filling knowledge gaps and the setting up of adequate response policies for the protection of citizens' health. The Action Plan asks for the development of innovative methodologies and tools for health risk and impact assessment, able to address the complexity of environment-health causal pathways and to effectively support decision-makers in setting up appropriate health protection policies. In this context, the need emerges for screening tools able to identify the most critical scenarios and the most pressing hazards, in order to identify those situations where a detailed assessment of health

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risks is advisable. In complex systems, where multiple stressors interact, many targets are momentarily involved and different health outcomes can be detected in the population, initial assessment efforts should be directed to the most relevant scenarios, with the aim of focusing the further risk assessment on the most critical situations (Menzie et al., 2007). This should be a “focusing exercise” aimed at guiding assessment efforts and resources towards those health stressors with the greatest potential effects on human health.

Several methodologies for screening and ranking chemical substances are currently available at the international level, developed in particular by US and EU agencies and research institutes with the aim of estimating the level of concern associated with different environmental pollutants and identifying therefore “priority substances” to be further investigated (IEH, 2004a). Most of these methodologies commonly make use of data on intrinsic properties of substances (physico-chemical properties and toxicological/ecotoxicological properties) or estimates of potential population exposure to these substances (e.g., calculated from production tonnages and potential applications/uses) and allow one to screen chemicals considering generic exposure scenarios. Examples of such methodologies are EURAM—European Union Risk Ranking Method (Hansen et al., 1999), CHEMS—Chemicals Hazard Evaluation for Management Strategies developed by US EPA (Davis et al., 1994; Swanson et al., 1997), and the Prioritisation Scheme developed by the MRC Institute for Environment and Health (IEH, 2004b). Moreover, the US Environmental Protection Agency has initiated the ExpoCast Programme to develop approaches and tools for screening, evaluating and classifying chemicals based on their potential for significant human exposure (Cohen-Hubal et al., 2010). In the framework of ExpoCast initiative, a multi-criteria method has been recently developed to prioritize the order in which chemicals should be further evaluated, based on inherent chemical properties and usage characteristics over the life cycle of chemicals (Mitchell et al., 2013).

However, it is more difficult to find in the literature structured and quantitative ranking methodologies for screening chemical substances in a site-specific context, suitable for identifying priority environmental chemical stressors on which further investigations and analyses should be focused.

Currently there is a lack of ranking methods using data on actual population exposure to environmental contaminants and on health outcomes measured in the population of interest, i.e. based on the exploitation of site-specific biomonitoring and health survey data rather than data about the intrinsic properties of chemical compounds and general exposure scenarios. Taking into account that the integration of data about environmental contamination, human exposure and health effects, if properly managed, could effectively support the exploration of environment and health relationships (Mather et al., 2004; Smolders and Schoeters, 2007), it is advisable to develop ranking methods based on the integration of such kinds of data. The choice to rely on monitoring data is further supported by recent efforts accomplished by EU Member States to collect consistent and harmonized environmental and biomonitoring data, as results of regional, national or international projects and initiatives aimed at investigating the environmental and health status for verifying legislation compliance or for research purposes (Smolders et al., 2008). Due to these achievements the opportunity arises to collect and integrate these data from different sources and to exploit them with the aim of identifying priority contaminants within a selected region.

Many authors recognize that spatial analysis is an important component of health risk assessment because most often the addressed problems are inherently spatial (e.g., Beale et al., 2008; Nuckols et al., 2004): concentrations of chemical contaminants have a specific and non-homogenous spatial distribution, fate and transport of chemicals occurs at different scales, and the regional distribution of targets (i.e., population groups) differ depending on demographic and socio-economic factors. The inclusion of the spatial dimension in the assessment and the comparison between different sub-areas in a regional assessment could effectively support the disclosure of complex relationships between environmental stressors and health outcomes. This is the founding principle of “ecological studies”, which are epidemiological observational studies in which the unit of analysis is a geographically defined group of individuals (Morgenstern and Thomas, 1993). Spatial analysis has been fruitfully coupled with decision analysis methods, such as Multi-Criteria Decision Analysis (MCDA), in the development of decision support approaches and tools to assist different environmental decision-making processes (e.g., Agostini et al., 2013; Yatsalo et al., 2011, 2012). The integration of spatially-based approaches with MCDA techniques proved to be effective in handling and assessing multidimensional data and constitute a promising approach for other application fields related to the management of environmental risks.

The main objective of this paper is to present a methodology for ranking environmental chemical stressors at the regional scale, based on the integration of the available monitoring data (environmental contamination, biomonitoring and health effect data) for the region of interest and adopting a spatially-based approach. The proposed methodology is aimed at supporting decision-makers in the evaluation of environmental and health data collected within the region of interest with the aim of identifying which chemical and associated health outcome should become the subject of a further detailed assessment. Moreover, the developed methodology aims to rank priority sub-areas within the region of interest, where further investigations might be needed.

To be able to integrate information from the environmental and the health domain, the proposed methodology adopts a Weight-of-Evidence (WoE) approach, which is based on the integration of individual Lines of Evidence (LoE) to derive a conclusion about the impacts or risks of a certain situation (Linkov et al., 2009). In particular, the need for structured, transparent, flexible and reproducible WoE methods (Weed, 2005) has guided the methodological development towards the application of Multi-Criteria Decision Analysis (MCDA) for implementing a quantitative WoE method. According to its screening purpose, the proposed methodology is focused on environmental pollutants as the only health stressors. This choice certainly implies a simplification of the assessment framework, because other relevant health determinants, such as socio-economic factors (e.g., lifestyle, education level, access to health services) or genetic factors are not considered. Recognizing the importance that these factors play on individuals' health status, their evaluation is transferred to more detailed assessment steps, when additional information about specific behaviours and conditions can be appropriately collected.

As a first step to verify its feasibility, the proposed methodology has been applied to a case-study in the Flemish region (northern part of Belgium), using data on soil contamination and biomarkers of exposure and effect measured in adolescents in the framework of the Flemish Biomonitoring Programme 2002–2006 (Den Hond et al., 2009; Schoeters et al., 2012).

2. Methods

2.1. Conceptual approach

The proposed methodology for ranking environmental chemical stressors at the regional scale is based on a quantitative Weight-of-Evidence approach. For each chemical stressor considered in the assessment, data from three Lines-of-Evidence (LoE) are integrated through a MCDA procedure based on a Fuzzy logic operator. MCDA was chosen because it allows the synthesis of multiple sources of information in a structured and transparent manner, with the aim of comparing several alternatives (Giove et al., 2009; Linkov et al., 2011). Background information on Weight-of-Evidence, Multi-Criteria Decision Analysis and Fuzzy Logic is provided in Section A of the Supplementary Material.

The selected LoEs provide information on a specific step of the continuous chain leading from the release of a chemical in the environment