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Review

Pathways and factors for food safety and food security at PFOS contaminated sites within a problem based learning approach

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HIGHLIGHTS

- Food of animal origin can play a pivotal role in food exposure in PFOS hot spot areas.
- Eggs from rural flocks may represent an emerging PFOS source.
- Advisories and implemented farming practice may reduce PFOS food intake by up to 75%.
- PFOS contaminated sites are problematic, due to its bioaccumulative feature.
- Level of soil contamination may represent a key factor both for food safety.

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ABSTRACT

Perfluorooctanesulfonic acid (PFOS) and related substances have been listed in Annex B of the Stockholm Convention. The implementation requires inventories of use, stockpiles, and environmental contamination including contaminated sites and measures for (risk) reduction and phase out. In most countries monitoring capacity is not available and therefore other approaches for assessment of contaminated sites are needed. Available informations about PFOS contamination in hot spot areas and its bio-accumulation in the food webs have been merged to build up a worst-case scenario We model PFOS transfer from 1 to 100 ng L^{-1} range in water to extensive and free-range food producing animals, also via the spread of contaminated sludges on agriculture soils. The modeling indicates that forages represented 78% of the exposure in ruminants, while soil accounted for >80% in outdoor poultry/eggs and pigs. From the carry-over rates derived from literature, in pork liver, egg, and feral fish computed concentration falls at 101, 28 and 2.7 ng g^{-1}, respectively, under the 1 ng L^{-1} PFOS scenario. Assuming a major consumption of food produced from a contaminated area, advisories on egg and fish, supported by good agriculture/farming practices could abate 75% of the human food intake. Such advisories would allow people to become resilient in a PFOS contaminated area through an empowerment of the food choices, bringing the alimentary exposure toward the current Tolerable Daily Intake (TDI) of 150 ng kg^{-1} body weight d^{-1} proposed by the European Food Safety Authority (EFSA).

Contents

Abbreviations: bw, body weight; dm, dry matter; EFSA, European Food Safety Authority; fw, fresh weight; MOS, margin of safety; OC, organic carbon; PFAS, poly- and perfluorinated alkyl substances; PFCAs, perfluorinated alkyl carboxilic acids; PFOS, perfluorooctane sulfonic acid; PFSAs, perfluorinated sulfonic acids; TDI, tolerable daily intake; US EPA, Environment Protection Agency of the United States; WWTP, waste water treatment plants.

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1. Introduction

Perfluoroalkane sulfonic acids (PFSAs) and perfluoroalkyl carboxylic acids (PFCAs) are highly persistent chemicals with a toxicological characterization continuously in progress (Joensen et al., 2009; Stahl et al., 2009; Lindström et al., 2011; Bull et al., 2014). Perfluorooctane sulfonate (PFOS), perfluorooctanoic acid (PFOA), and other long-chained PFSAs (with 6 or more perfluorinated carbons) and PFCAs (with 7 or more perfluorinated carbons) bioaccumulate and biomagnify despite their water solubility (Martin et al., 2004; Conder et al., 2008). Therefore, in May 2009 perfluorooctane sulfonate (PFOS) and PFOS related substances were listed as the first PFAS in the Stockholm Convention as Persistent Organic Pollutant (POP) (Stockholm Convention, 2011, 2012), to be addressed globally within the management frame of the Convention. Now, many of the 179 countries which are parties to the Convention have started to establish inventories for PFOS use, stockpiles and environmental contamination including contaminated sites. The largest PFOS production and use took place between 1980 and 2001 with a production volume of approx. 4500 t yr^{-1} (Paul et al., 2010). After 3 M stopped the PFOS production the volume dropped dramatically to approximately 100–200 t production after 2002 with production volume largely in China (Lim et al., 2011; Zhang et al., 2012) and minor production in Germany and Italy (Oliaei et al., 2013). Therefore, in addition to managing current production and use (European Parliament, 2006), the major management task to appropriately address PFOS are remaining stockpiles and the legacies of the historic production and contaminated sites along the life cycle (Stockholm Convention, 2011). This includes the pollution from (former) production sites (Oliaei et al., 2013; Bao et al., 2011; D'Hollander et al., 2011) but also sites where PFOS has been used in productions (e.g. chromium plating, paper or textile impregnation industries). One important sink of PFOS and long chain PFCAs were/are here the industrial sludges and municipal sewage sludge recovered from contaminated influents: the PFOS coefficient of absorption to the organic carbon makes sludges and derived biosolids 3 order of magnitude more contaminated than the influent water (Arvaniti et al., 2014). The application of such PFSAs/PFCAs containing sludges as "bio-solids" has resulted in contaminated areas and some of the sludge application impacted pasture land (Skutlarek et al., 2006; Wilhelm et al., 2008; Lindström et al., 2011; Oliaei et al., 2013). Furthermore, the use of firefighting foams has resulted in many PFOS contaminated sites at firefighting practice areas and areas with fire incidents where PFOS containing foams have been used (Moody and Field, 2000; Weber et al., 2010; Houtz et al., 2013). Due to their water solubility, PFOS and other long chain PFSAs and PFCAs are mobilized and released from landfills in water bodies as consequence of the progressive saturation of the binding sites linked to the organic matter of the soil (Huset et al., 2008, 2011; Busch et al., 2010; Weber et al., 2011). The Stockholm Convention inventory guidance for PFOS includes therefore a dedicated chapter on the inventory of PFOS contaminated sites (Stockholm Convention, 2012). One challenge of the Convention implementation is that developing countries have hardly any analytical capacity for PFOS and other per- and poly-fluoro alkyl substances (PFAS) and only a limited amount of studies reported on PFOS levels in developing countries but measured in industrial countries (Guruge et al., 2005; Orata et al., 2009; Sindiku et al., 2013). To our knowledge no study has investigated PFOS/PFAS such sites in developing countries. However, from risk assessment perspective the affected population at particular contaminated sites might show exposure levels higher than the TDI of 150 ng kg^{-1} bw d^{-1} set by EFSA for PFOS (EFSA, 2008). Locally produced and consumed food of animal origin may play a relevant role in determining potential over-exposures with respect to such guidance value, as matter of the bioaccumulative behavior of PFOS and of the food consumption habits of the target population. Within a comprehensive risk assessment for human health, it seems mandatory to include all potential food exposure pathways (Oliaei et al., 2013), as far human intake might not acknowledge feral fish and drinking water only as the major contributing food items in a hot spot area (Minnesota Health Department, 2008). Owing to the above, in this paper we aimed to exploit the driving questions arising from the health-based risk management option in a potential emblematic PFOS hot spot rural area. One goal is to provide policy makers and risk managers a PFOS exposure scenario which includes the major pathways and known factors that may play a pivotal role in enhancing or mitigating rural community PFOS food intake in contaminated site and the current state of knowledge on fate and bioaccumulation of PFOS in the food webs. Such a summary of food-related exposure pathways, bioaccumulation factors and carry-over rates might be beneficial in particular for countries without analytical capacity and limited monitoring options. More in general, a cost-effective risk-oriented approach would consist on enabling communities to become PFOS-resilient in a contaminated area through an empowerment of their local water and food choices (WHO Regional Office for Europe, 2013).