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Applicability of western chemical dietary exposure models to the Chinese population

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ABSTRACT

A range of exposure models, which have been developed in Europe and North America, are playing an increasingly important role in priority setting and the risk assessment of chemicals. However, the applicability of these tools, which are based on Western dietary exposure pathways, to estimate chemical exposure to the Chinese population to support the development of a risk-based environment and exposure assessment, is unclear. Three frequently used modelling tools, EUSES, RAIDAR and ACC-HUMANsteady, have been evaluated in terms of human dietary exposure estimation by application to a range of chemicals with different physicochemical properties under both model default and Chinese dietary scenarios. Hence, the modelling approaches were assessed by considering dietary pattern differences only. The predicted dietary exposure pathways were compared under both scenarios using a range of hypothetical and current emerging contaminants. Although the differences across models are greater than those between dietary scenarios, model predictions indicated that dietary preference can have a significant impact on human exposure, with the relatively high consumption of vegetables and cereals resulting in higher exposure via plants-based foodstuffs under Chinese consumption patterns compared to Western diets. The selected models demonstrated a good ability to identify key dietary exposure pathways which can be used for screening purposes and an evaluative risk assessment. However, some model adaptations will be required to cover a number of important Chinese exposure pathways, such as freshwater farmed-fish, grains and pork.

1. Introduction

Many chemicals are released into the environment which have the potential to be taken up into organisms, where they may be transferred through food chains and potentially threaten human health. Human exposure to chemicals can occur via direct and indirect exposure. Indirect human exposure via the environment comprises intake through inhalation, drinking water and diet. The evaluation and quantification of human exposure to chemicals through multimedia exposure pathways is required for both priority setting and risk assessment, and is becoming increasingly important in the global assessment of chemicals (Undeman and McLachlan, 2011). In many previous studies, diet has been highlighted as an important human exposure pathway for a wide range of organic chemicals, such as polychlorinated dibenzo-p-dioxins, polychlorinated dibenzo-furans (PCDD/F, dioxins) and polychlorinated biphenyls (PCBs). For some chemicals, dietary exposure has been demonstrated to account for more than 90% of total human exposure (Domingo et al., 2012; Harrad et al., 2004; Herzke et al., 2013; Kiviranta et al., 2004; Vestergren et al., 2012; Xia et al., 2010; Zhou et al., 2012). However, owing to limited time and resource, many existing chemicals still lack detailed information on human exposure via the consumption of food, which makes risk assessment both difficult and incomplete. Therefore, multimedia fate modelling approaches have been demonstrated to be helpful to screen and prioritize chemical compounds of concern for the environment and human health (Rodan et al., 1999).

A number of different models are currently used in Europe and North America to assess human dietary exposure and risk. For example, the European Union System for the Evaluation of Substances (EUSES), USEtox, CALTOX, ACC-HUMAN and the Risk Assessment Identification And Ranking (RAIDAR) models have been used to estimate human exposure to chemicals via the environment (Arnot and Mackay, 2008; Czub and McLachlan, 2004; McKone et al., 2007; Rosenbaum et al., 2008; Vermeire et al., 2005). All these models represent the current state of science and

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have been developed to meet the needs of chemical risk assessment for government regulators, industry and academia in developed countries (Fryer et al., 2006). The key differences between the models are their parameterization of geographic and environmental conditions, human receptor characteristics, and treatment of the food web (Arnot et al., 2010).

As a developing country China has become one of the most important chemical manufacturing nations in the world, and there are thousands of chemicals used in commerce daily. Under rapid industrialization there are potential health risks associated with chemical residues in food resources which may be significant in China (L. Zhang et al., 2013). Unfortunately, prioritization schemes and risk assessment procedures for these chemicals in China are currently underdeveloped and national technical guidance for risk assessment has not yet been established, nor have the modelling tools required (Wang et al., 2012). As a result, there is an urgent need for China to develop suitable approaches and modelling tools.

The models and approaches currently being used in developed countries could significantly help for both priority setting and risk assessment for chemical management in China, and much effort has been made to adapt Western-developed models to estimate emission and fate of persistent organic chemicals (POPs) in China, mainly by the revision of environmental parameters and emission scenarios (Xu et al., 2013; Q.Q. Zhang et al., 2013; Zhang et al., 2014). However, human exposure to organic pollutants has also been shown to be highly variable in different regions of the world (Undeman et al., 2010). Recent measurement campaigns have found large variations of daily intake in the relative contributions from different food groups among regions in China for a number of POPs, which are different from Western countries (Shi et al., 2013; Yu et al., 2013; L. Zhang et al., 2013). However, the uncertainty from dietary patterns and its potential impact on human exposure have not been explored for Chinese population. Therefore, this study was designed to assess whether Western-based dietary modelling tools could be directly applied to China or how they could be reconfigured to investigate Chinese exposure scenarios to support environmental and human risk-based assessments.

In order to model human dietary exposure to chemicals in China, it is important to understand which models are potentially suitable and how they can be adapted to the Chinese population, or indeed need to be modified. Therefore, the aims of this study are: (1) to compare three commonly used modelling approaches and evaluate their performance in Europe and Canada to assess dietary exposure routes; (2) to identify dominant dietary exposure pathways both under Western and Chinese scenarios and explore the impact of dietary preferences for a wide range of hypothetical chemicals; (3) to explore the potential application of these models to China. To pursue these objectives, firstly, the dominant dietary exposure pathway was identified for a wide range of hypothetical chemicals covering chemical partitioning space defined by their octanol–water (K_{OW}) and octanal–air (K_{OA}) partition coefficients for each of the three models. Secondly, the three models were evaluated by applying them to a range of legacy and emerging contaminants with different properties under both Western and Chinese scenarios. Finally, this analysis was used to identify potential adaptions to facilitate better risk assessment in China.

2. Methods

2.1. Model overview

RAIDAR 2.0, EUSES (spreadsheet version 1.24) and ACC-HUMANsteady (a steady-state version of ACC-HUMAN) were selected to be assessed in this study. Each model was accessed from their respective websites; namely the Canadian Centre for Environment Modelling and Chemistry (http://www.trentu.ca/academic/aminss/envmodel/models/RAIDAR100.html), Netherlands Centre for Environmental Modelling (http://cem-nl.eu/eutgd.html) and Department of Applied Environment Science, Stockholm University (http://www.itm.su.se/page.php?pid=117). These models are described in detail elsewhere (Arnot et al., 2006; Czub and McLachlan, 2004; Vermeire et al., 1997).

In general, the three models are conceptually similar as they are all based on the Mackay-type steady-state fugacity-based box models as summarized in Table 1 (Mackay et al., 2009). EUSES is a harmonized quantitative risk assessment tool, which is designed to support decisions for regulators and industry to undertake chemical risk assessments (Vermeire et al., 2005, 1997). Details are given in the EU Technical Guidance Document (TGD) (European Commision, 2003). Default values for food consumption rates are representative of the highest country-average levels among the EU member states. RAIDAR and ACC-HUMANsteady are research models based on more recent research in exposure assessment (Arnot et al., 2010; Czub and McLachlan, 2004; Undeman and McLachlan, 2011). These models were chosen as they are widely used in Europe, Canada and U.S. for screening purposes using assumed 'generic' environment.

However, one significant difference among the three models is the treatment of food web bioaccumulation and transfer and thus their predictions for substances in various food groups vary (Arnot et al., 2010). EUSES employs simple empirical regression models to estimate concentrations in organisms from concentrations in environmental media, whilst RAIDAR and ACC-HUMANsteady use mechanistic models to address the bioaccumulation processes. Mechanistic bioaccumulation models incorporate chemical specific biomagnification and biotransformation processes, resulting in more refined exposure estimation, provided additional input requirements are available (Arnot et al., 2010). Different food groups are considered according to locally applicable food chains. Additionally, EUSES includes a spatial assessment of

Table 1
Comparison of three selected models.

Model	EUSES	RAIDAR	ACC-HUMANsteady
Sponsor	RIVM European Commission	Environment Canada, Health Canada, Industry	Baltic Sea Research Institute, Stockholm University
Source distance	Near field and far field	Far field	Far field
Human exposure pathways	Inhalation, water, fish, meat, dairy and vegetables (root, leaf)	Inhalation, water, fish, meat (poultry, beef and pork), vegetables (root, leaf)	Inhalation, water, beef, dairy, fish, vegetables (root, leaf, fruit and grain)
Exposure algorithm	Empirical regression models to estimate concentrations in organisms in equilibrium with environmental media	Combined fate and food web mass balance models for estimating exposure and ranking	Steady-state, mechanistic-based fugacity approach
Data input	Physical–chemical data and chemical emission information for initial screening assessment	Physical–chemical data and degradation half-life parameters from databases or QSARs	Physical–chemical data and environmental concentration