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Actor modelling and its contribution to the development of integrative strategies for management of pharmaceuticals in drinking water☆

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ABSTRACT

Widespread presence of human pharmaceuticals in water resources across the globe is documented. While some, but certainly not enough, research on the occurrence, fate and effect of pharmaceuticals in water resources has been carried out, a holistic risk management strategy is missing. The transdisciplinary research project "start" aimed to develop an integrative strategy by the participation of experts representing key actors in the problem field "pharmaceuticals in drinking water". In this paper, we describe a novel modelling method, actor modelling with the semi-quantitative software DANA (Dynamic Actor Network Analysis), and its application in support of identifying an integrative risk management strategy. Based on the individual perceptions of different actors, the approach allows the identification of optimal strategies. Actors' perceptions were elicited by participatory model building and interviews, and were then modelled in perception graphs. Actor modelling indicated that an integrative strategy that targets environmentally-responsible prescription, therapy, and disposal of pharmaceuticals on one hand, and the development of environmentally-friendly pharmaceuticals on the other hand, will likely be most effective for reducing the occurrence of pharmaceuticals in drinking water (at least in Germany where the study was performed). However, unlike most other actors, the pharmaceutical industry itself does not perceive that the production of environmentally-friendly pharmaceuticals is an action that helps to achieve its goals, but contends that continued development of highly active pharmaceutical ingredients will help to reduce the occurrence of pharmaceuticals in the water cycle. Investment in advanced waste or drinking water treatment is opposed by both the wastewater treatment company and the drinking water supplier, and is not mentioned as appropriate by the other actors. According to our experience, actor modelling is a useful method to suggest effective and realisable integrative risk management strategies in complex problem fields that involve many societal actors.

Introduction

Widespread presence of human pharmaceuticals and their metabolites in the water cycle and sporadic occurrence even in drinking water have been documented across the globe, resulting in increased attention in public, media and research (BLAC, 2003; Daughton & Ternes, 1999; Kümmerer, 2007a; Nikolaou, Meric, & Fatta, 2007; Robinson, Junqua, Van Coillie, & Thomas, 2007). Even though measured concentrations are often in parts per billion or parts per trillion, they can be a hazard since drugs are designed to have physiological effects in organisms at low concentrations. Approximately 38 000 tons of pharmaceuticals are used every year in Germany (UBA, 2005). Hormones, antibiotics, blood lipid regulators, analgesics, beta-blockers, antidepressants, diagnostic contrast media, and antiepileptic and cytostatic drugs have been detected in the aquatic environment (BLAC, 2003), and relate to their large prescription volumes. In 2005, drug sales grew by 5% and 7% in North America and Europe, respectively; in August 2005, more than 140 000 bioactive compounds were in the different phases of drug research and development worldwide (Daughton, 2005). European Union and the United States laws require an assessment of potential risks to the environment as part of the licence application process for new medicinal products (EMEA, 2006; FDA, 1998). In Canada, environmental assessment regulations for pharmaceuticals are currently under development (Beck, 2007). Nevertheless, when the possibility of an environmental risk

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cannot be excluded, benefits for patients obtain priority and a denial of marketing authorisation is not likely (see EMEA, 2006, and FDA, 1998 for detailed information).

Pathways of pharmaceuticals into the aquatic environment

Pharmaceuticals (drugs) usually enter the aquatic environment following normal usage (see Fig. 1): After administration, a large portion passes through patients' bodies unmodified or partly metabolised (depending on the individual, pharmaceutical agent and dosage) and are excreted with urine and faeces into wastewater (Heberer, 2002). The residue that passes through sewage treatment plants discharges into surface water. They also reach wastewater through disposal of unused or outdated drugs. Drugs disposed of to landfill may also drain into ground and surface water. In addition, drugs may enter the aquatic environment via leakage from sewer networks (Ternes, 1998, 2000). Currently, it is not possible to estimate the relative contribution of excreted and disposed drugs to environmental loadings, as precise data about the consumption of pharmaceuticals are not available and disposal routes remain highly uncertain. Chemical analysis cannot currently distinguish excreted drugs from drugs that were disposed of (Daughton, 2007). Despite this, Ruhoy and Daughton (2007) have developed a new methodology for assessing the relative impact of drug disposal versus excretion on the occurrence of pharmaceuticals in the environment at the scale of local communities using inventory data collected by coroner offices in the United States. In Germany, 16% of the population dispose of tablets via domestic sewage at least occasionally and as many as 44% do this with liquid drugs according to a survey by Götz and Keil (2007).

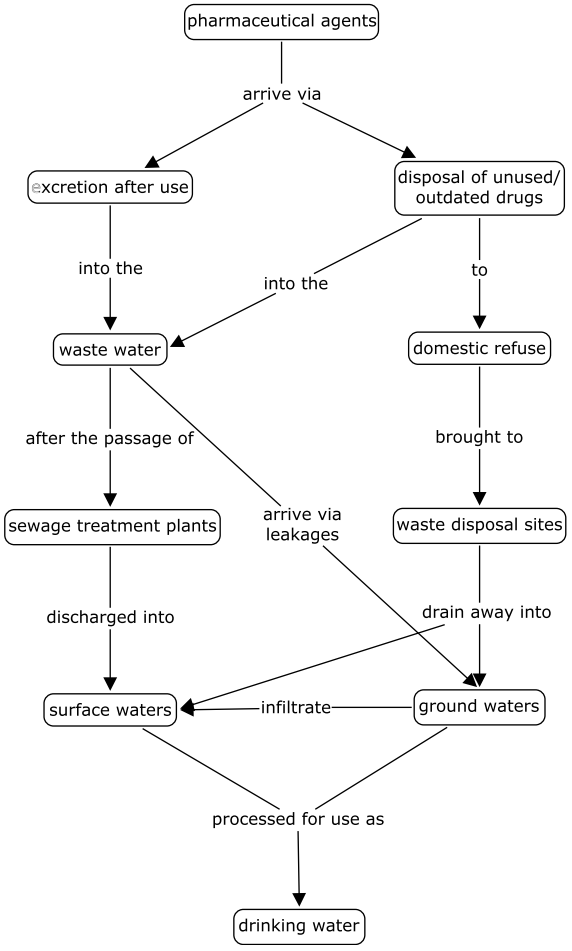

Fig. 1. Most important entry paths of human pharmaceuticals into the water cycle (modified after Ternes, 2000).

Evidence of adverse effects of pharmaceuticals in the environment

Adverse effects on aquatic organisms have been detected for a large number of pharmaceutical agents at environmental concentrations (Khetan & Collins, 2007; Robinson, Junqua, Van Coillie, & Thomas, 2007). In case of a mixture of numerous endocrine pharmaceuticals that bind to the alpha human oestrogen receptor, and for a number of beta-blockers, the toxicological effects of the pharmaceuticals are additive (Khetan & Collins, 2007). With respect to adverse health effects of pharmaceutical agents in drinking water, there is only very scant information. Although environmental concentrations are low compared to therapeutic doses so that most scientists assume that they do not pose an appreciable risk to human health, it was acknowledged that there are exceptions, e.g. oestrogens, genotoxic antineoplastics or compounds with high potential for bioaccumulation like diclofenac (Khetan & Collins, 2007). Pregnant women and their babies, as well as children, are at particular risk. During pregnancy, women would ingest 13% of a clinical dose of the synthetic oestrogen ethynyl estradiol via drinking water, a hormone that is absolutely contraindicated during pregnancy (Collier, 2007). Children are at risk by pharmaceutical agents in drinking water that are contraindicated for children.

EPA (2008) provides a compilation of literature references on pharmaceuticals (and personal care products) in the environment. Occurrence, fate and toxicological effects of pharmaceuticals in the environment have been covered by many publications (Heberer, 2002; Khetan & Collins, 2007; Kümmerer, 2007a; Robinson et al., 2007).

Table 1
Actions and actors of the three main strategic approaches that were designed in the research project "start" for reducing the occurrence of pharmaceuticals in the water cycle.

Action [Actor]
Technical approach
Implement advanced drinking water treatment (e.g. granular activated carbon filtration) [Drinking water supplier]
Install advanced wastewater treatment [Sewage treatment company]
Install separate treatment of wastewater from hospitals and nursing homes [Owner of facilities]
Install sewage separation [Municipality]
Behavioural approach
Avoid over-prescription [Physician]
Avoid prescription of pharmaceuticals with unsound environmental behaviour [Physician]
Develop an environmental classification list for pharmaceuticals [Scientific institute]
Establish increased co-payments for pharmaceuticals [Ministry of Health]
Include topic in retraining of physicians and pharmacists [Professional association]
Initiate a discourse with medical professionals [PR-Agency]
Introduce electronic health card [Ministry of Health]
Legislate binding standard disposal for pharmaceuticals [Legislator]
Offer varying packaging sizes/starter packs [Pharmaceutical industry]
Operate a communication campaign for proper disposal of unused/outdated pharmaceuticals [Government/Health insurance]
Prescribe drug-free therapies [Physician]
Print advice for proper disposal on packaging and instruction leaflet [Pharmaceutical industry]
Pharmaceutical agent approach
Couple marketing authorisation and environmental risk assessment more strongly [Authorisation Agency]
Establish thematic programmes on pharmaceutical and organic chemistry at universities [German Research Foundation]
Extend patent terms for sustainable pharmaceuticals [Legislator]
Initiate specific research programmes for the development of sustainable pharmaceuticals [National Research Programmes]
Offer awards and competitions in sustainable pharmacy [Federal Environment Agency]