Pharmaceuticals in the environment
- The global perspective

Dr. Tim aus der Beek (IWW Water Centre)

Workshop: Pharmaceuticals and priority chemicals in the Highlands and Islands environment
Inverness, 21st June 2017
How do pharmaceuticals enter the environment?

Consumer

Pharmaceutical Industry

Hospital

Agriculture/Aquaculture
How do pharmaceuticals enter the environment?

Waste water treatment plants (WWTP)

Waste / Wastewater

Sludge / Manure
How do pharmaceuticals enter the environment?

- Drinking water
- Surface and Groundwater
- Agricultural soil
Motivation

- Multiple studies have shown that pharmaceuticals are occurring ubiquitarily in the environment of industrialized countries.
- In developing and emerging countries?
- Integration of the topic as emerging pollutants in UNEP-SAICM (www.saicm.org).
- IWW Water Centre and adelphi are conducting a study to determine the state of knowledge on the global scale.
Endnote© database:

- **1016 publications** reporting MECs of pharmaceuticals in various countries (plus 139 review articles)

Publications collected by
- Database search (ISI Web of Knowledge™, library catalogues, etc.)
- Internet
- Contacting of stakeholders (41 in 18 countries)
- Research projects (NORMAN, KNAPPE, FATE-SEES included)

Types of publication
- Mostly English-language scientific papers
- Relative little governmental reports
- German-, Chinese-, French-, Russian-, Slovenian-, Portuguese-, Dutch-, Swedish- and Spanish-language publications evaluated
# MEC Database

(measured environmental concentrations)

- 123,761 MEC entries from 1016 publications

## Count | Matrix\_English
---|---
1.891 | Sewage urban (untreated)
729 | Sewage industrial (untreated)
2.889 | Sewage hospital (untreated)
351 | Sewage hospital (treated)
13.219 | WWTP inflow (untreated)
27.579 | WWTP effluent (treated)
2.672 | WWTP sludge
3.245 | Surface Water - unspecific
50.686 | Surface Water - River/Stream
1.711 | Surface Water - Lake
1.420 | Surface Water - Sea or Ocean
467 | Surface Water - Aquaculture
743 | Surface Water - Estuary
485 | Riverbank filtration
3.304 | Groundwater
1.713 | Well Water (untreated)
382 | Tap water
3.831 | Drinking Water

## Count | Matrix\_English
---|---
283 | Sediment - unspecific
1.247 | Sediment - River/Stream
612 | Sediment - Lake
55 | Sediment - Sea or Ocean
184 | Sediment - Aquaculture
155 | Sediment - Estuary
9 | Suspended particulate matter - unspecific
5 | Suspended particulate matter - Estuary
146 | Suspended particulate matter - Sewage
12 | Suspended particulate matter - Sea or Ocean
362 | Suspended particulate matter - River/Stream
15 | Rain
1.295 | Soil
372 | Soil Water
999 | Manure - liquid
580 | Manure - dung
18 | Dust
95 | Unknown

MEC: measured environmental concentration
Database Analyses

Questions to be answered:
- On a global scale, where have pharmaceuticals been found in the environment?
- How many and what kind of pharmaceuticals have been found?
- Are the same pharmaceuticals detected in each UN regional group?
- What is the source of the pharmaceuticals found?
- At which concentrations are pharmaceuticals found in the environment?
- Can pharmaceuticals have ecotoxicological effects at these concentrations?
In 71 countries (covering all 5 UN regional groups), pharmaceuticals have been detected in the environment. (concentration of at least one MEC in one matrix > detection limit)
In each UN regional group, \(\geq 38\) different pharmaceuticals have been found in surface water / groundwater / drinking water / tap water.
In every UN regional group, pharmaceuticals have been found in drinking water / tap water.
Worldwide, 559 pharmaceuticals or their transformation products have been found in sewage or WWTP influent/effluent/sludge.
713 pharmaceuticals have been analysed (of which 142 are transformation products).

631 have been found above their detection limits in the environment (of which 127 are transformation products).

631 pharmaceuticals detected (of 713 analysed)
Are the same pharmaceuticals detected in each UN regional group?

- **126 (205)** in EEC
- **249 (313)** in Asia-Pacific
- **574 (646)** in WEOC
- **55 (84)** in GRULAC
- **40 (59)** in Africa
### Data Analyses

Are the same pharmaceuticals detected in each UN regional group?

- **16 pharmaceuticals were found in surface water / groundwater / drinking / tap water in each of the five UN regional groups**

<table>
<thead>
<tr>
<th>Name</th>
<th>Therapy Group</th>
<th>Number of Countries with Positive Detection in Surface Water, Groundwater, Drinking Water</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>African Group</td>
</tr>
<tr>
<td>Diclofenac</td>
<td>Analgesics</td>
<td></td>
</tr>
<tr>
<td>Carbamazepine</td>
<td>Antiepileptic drugs</td>
<td>3</td>
</tr>
<tr>
<td>Ibuprofen</td>
<td>Analgesics</td>
<td>3</td>
</tr>
<tr>
<td>Sulfamethoxazole</td>
<td>Antibiotics</td>
<td>5</td>
</tr>
<tr>
<td>Naproxen</td>
<td>Analgesics</td>
<td>2</td>
</tr>
<tr>
<td>Estrone</td>
<td>Estrogen</td>
<td>1</td>
</tr>
<tr>
<td>17-beta-Estradiol</td>
<td>Estrogen</td>
<td>2</td>
</tr>
<tr>
<td>17-alpha-Ethinylestradiol</td>
<td>Estrogen</td>
<td>1</td>
</tr>
<tr>
<td>Trimethoprim</td>
<td>Antibiotics</td>
<td>2</td>
</tr>
<tr>
<td>Paracetamol</td>
<td>Analgesics</td>
<td>1</td>
</tr>
<tr>
<td>Clofibric acid</td>
<td>Lipid-lowering drugs</td>
<td>1</td>
</tr>
<tr>
<td>Ciprofloxacin</td>
<td>Antibiotics</td>
<td>1</td>
</tr>
<tr>
<td>Ofloxacin</td>
<td>Antibiotics</td>
<td>1</td>
</tr>
<tr>
<td>Estriol</td>
<td>Estrogen</td>
<td>1</td>
</tr>
<tr>
<td>Norfloxacin</td>
<td>Antibiotics</td>
<td>1</td>
</tr>
<tr>
<td>Acetylsalicylic acid</td>
<td>Analgesics</td>
<td>1</td>
</tr>
</tbody>
</table>
Data Analyses

What kind of pharmaceuticals have been found in each UN groups?

- Analgesics
- Lipid-Lowering Drugs
- Estrogens
- Other
Data Analyses

What is the source of the pharmaceuticals found in the environment?

- Urban areas are a major contributor.
- Discharge from manufacturing, animal husbandry, and aquaculture are important regionally.
Data Analyses

Case studies Scotland

Measurement of 9 pharmaceuticals in two Scottish rivers

(Loos et al. 2008)
Data Analyses

Case studies Scotland

Measurement of 3 pharmaceuticals in wastewater, surface water, drinking water in Northern Scotland

(Nebot et al. 2007)
Measurement of range of 4 estrogens in 8 soils (Hartwood)

(Zhang et al. 2011)
## Effects of human medicines in the environment – case studies

<table>
<thead>
<tr>
<th>Medicine</th>
<th>Type</th>
<th>Species</th>
<th>Effect</th>
<th>Study Type</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>17α-Ethinylestradiol</td>
<td>Synthetic estrogen</td>
<td>Fathead minnow (<em>Pimephales promelas</em>)</td>
<td>Population collapse due to feminization of male fish</td>
<td>Whole-lake experiment</td>
<td>Kidd et al. 2007</td>
</tr>
<tr>
<td>Fluoxetine</td>
<td>Antidepressant</td>
<td>Leopard Frog (<em>Rana pipiens</em>)</td>
<td>Delayed tadpole development</td>
<td>Laboratory</td>
<td>Foster et al. 2010</td>
</tr>
<tr>
<td>Enrofloxacin, Ciprofloxacin</td>
<td>Antibiotics</td>
<td>Cyanobacterium (<em>Anabaena flosaquae</em>)</td>
<td>Duckweed (<em>Lemna minor</em>)</td>
<td>Growth inhibition</td>
<td>Laboratory</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Ebert et al. 2011</td>
<td></td>
</tr>
</tbody>
</table>
Data Analyses

Can pharmaceuticals have ecotoxicological effects at these concentrations?

- **Average Diclofenac concentration in surface waters**
  (only monitoring campaigns in which “single values” or “average values” with known sample size n are reported)

<table>
<thead>
<tr>
<th>Country</th>
<th>Average (weighted)</th>
<th>Unit</th>
<th>Samples (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pakistan</td>
<td>1,550 µg/l</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Brazil</td>
<td>0,707 µg/l</td>
<td></td>
<td>44</td>
</tr>
<tr>
<td>Côte d'Ivoire</td>
<td>0,540 µg/l</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>Ukraine</td>
<td>0,438 µg/l</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Spain</td>
<td>0,268 µg/l</td>
<td></td>
<td>204</td>
</tr>
<tr>
<td>Côte Republic</td>
<td>0,200 µg/l</td>
<td></td>
<td>68</td>
</tr>
<tr>
<td>Germany</td>
<td>0,164 µg/l</td>
<td></td>
<td>4137</td>
</tr>
<tr>
<td>Slovakia</td>
<td>0,152 µg/l</td>
<td></td>
<td>134</td>
</tr>
<tr>
<td>Poland</td>
<td>0,126 µg/l</td>
<td></td>
<td>40</td>
</tr>
<tr>
<td>Malaysia</td>
<td>0,117 µg/l</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Greece</td>
<td>0,104 µg/l</td>
<td></td>
<td>25</td>
</tr>
<tr>
<td>Belgium</td>
<td>0,103 µg/l</td>
<td></td>
<td>14</td>
</tr>
<tr>
<td>Sweden</td>
<td>0,090 µg/l</td>
<td></td>
<td>113</td>
</tr>
<tr>
<td>Cyprus</td>
<td>0,088 µg/l</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>South Africa</td>
<td>0,085 µg/l</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Switzerland</td>
<td>0,077 µg/l</td>
<td></td>
<td>183</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td></td>
<td>...</td>
</tr>
</tbody>
</table>
At which concentration are pharmaceuticals found in the environment?

- **Maximum 17-α-Ethinylestradiol (EE2, birth control pill) concentrations in surface waters**

<table>
<thead>
<tr>
<th>Country</th>
<th>Maximum Conc Unit</th>
<th>Publication</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brazil</td>
<td>5,900 µg/l</td>
<td>Machado (2010)</td>
</tr>
<tr>
<td>Spain</td>
<td>0,280 µg/l</td>
<td>Camacho et al. (2010)</td>
</tr>
<tr>
<td>USA</td>
<td>0,145 µg/l</td>
<td>Snyder et al. (2007)</td>
</tr>
<tr>
<td>Switzerland</td>
<td>0,120 µg/l</td>
<td>Gälli et al. (2009)</td>
</tr>
<tr>
<td>Germany</td>
<td>0,117 µg/l</td>
<td>Vallejo et al. (2013)</td>
</tr>
<tr>
<td>Slovenia</td>
<td>0,080 µg/l</td>
<td>Avbersek et al. (2013)</td>
</tr>
<tr>
<td>Israel</td>
<td>0,036 µg/l</td>
<td>Barel-Cohen et al. (2006)</td>
</tr>
<tr>
<td>Vietnam</td>
<td>0,028 µg/l</td>
<td>Duong et al. (2010)</td>
</tr>
<tr>
<td>China</td>
<td>0,027 µg/l</td>
<td>Chen et al. (2007)</td>
</tr>
</tbody>
</table>

...
At which concentration are pharmaceuticals found in the environment?

![Bar chart showing concentrations of Diclofenac and Carbamazepine in different regions.](chart.png)
Conclusions

- Pharmaceuticals occur globally in the environment (not just in industrialized countries):
  - Detected in 71 countries covering all 5 UN regional groups
  - Data availability for emerging and developing countries increasing, but still lower than in western countries

- In most countries, certain pharmaceuticals prevail at concentrations above PNEC in surface waters, suggesting adverse ecotoxicological effects in these locations.

- Different pharmaceutical groups have been in focus of monitoring in different UN regions, e.g. antibiotics in Asia and estrogens in Africa.

- Urban wastewater discharge is the dominant emission pathway, while discharge from manufacturing, animal husbandry and aquaculture are important regionally.

- Available data on production/consumption not sufficient for regional analysis of relevant pharmaceuticals.
Pharmaceuticals in the environment
Occurrence, effects, and options for action

Pharmaceuticals are known to occur widely in the aquatic environment of industrialized countries. In developing and emerging countries, information on the occurrence of pharmaceuticals in the environment has become more readily available in recent years. However, a concise picture on the relevant pharmaceuticals, their prevailing concentrations in the environment, and their potential effects on human and ecosystem health is still elusive in these countries.

The International Society of Doctors for the Environment has suggested the topic “Environmentally Persistent Pharmaceutical Pollutants” (EPPP) for nomination as an emerging issue under the Strategic Approach on International Chemicals Management (SAICM) of the United Nation Environmental Programme (UNEP).

As the basis for further considerations and more concrete discussions, the goal of the current project is to clearly define the state of knowledge on the global relevance of pharmaceuticals in the environment.

The main tasks of the project are thus to

- compile Measured Environmental Concentrations (MEC) of human and veterinary pharmaceuticals from all five UN regional groups,
- compare regional consumption data and future trends,
- assess the relevance of different emission pathways (production, use, disposal),
- assess the role of infrastructure, population, pharmaceutical availability, agricultural practice, etc., on the emissions of pharmaceuticals into the environment,
- provide databases and maps that could illustrate the global relevance of pharmaceuticals in the environment as an emerging issue, and
- prepare possible activities for inclusion into the global plan for action.
PHARMACEUTICALS IN THE ENVIRONMENT—GLOBAL OCCURRENCES AND PERSPECTIVES

Tim aus der Beek,*† Frank-Andreas Weber,† Axel Bergmann,† Silke Hickmann,‡ Ina Ebert,‡ Arne Hein,‡ and Anette Küster‡

†IWW Water Centre, Department of Water Resources Management, Mülheim an der Ruhr, Germany
‡Section IV 2.2 Pharmaceuticals, Washing and Cleaning Agents, Umweltbundesamt (German Federal Environment Agency), Dessau, Germany

(Submitted 27 February 2015; Returned for Revision 3 July 2015; Accepted 11 December 2015)

Abstract: Pharmaceuticals are known to occur widely in the environment of industrialized countries. In developing countries, more monitoring results have recently become available, but a concise picture of measured environmental concentrations (MECs) is still elusive. Through a comprehensive literature review of 1016 original publications and 150 review articles, the authors collected MECs for human and veterinary pharmaceutical substances reported worldwide in surface water, groundwater, tap/drinking water, manure, soil, and other environmental matrices in a comprehensive database. Due to the heterogeneity of the data sources, a simplified data quality assessment was conducted. The database reveals that pharmaceuticals or their transformation products have been detected in the
Acknowledgement

- We thank UBA und BMUB for funding this research within UFOPLAN under FKZ 3712 65 408.

- We like to thank the following colleagues for support and valuable discussions:
  - BMUB: V. Karavezyris, J. Emig
  - Adelphi: G. Gruettner, A. Carius

Dr. Tim aus der Beek
IWW Water Centre
t.ausderbeek@iww-online.de

CONTACT

Moritzstraße 26 | 45476 Mülheim an der Ruhr
Germany
Phone | +49 (0)208-403 03-0
Fax | +49 (0)208-403 03-80
E-Mail | info@iww-online.de
Web | www.iww-online.de