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Life cycle assessment at the scale of France on Human health and aquatic environment of micropollutants released by wastewater treatment plants

Quentin Aemig, Arnaud Hélias, Dominique Patureau
Micropollutants: an old story!

- Industries
- Agriculture
- Cities
- Food
- Plastics
- Drugs
- Household products
- Cosmetics


Briand et al. 2018
Environmental contamination

Transfer of contamination:
• Sorption to sludge
• Volatilization

Elimination from water:
• Physicochemical or biological transformation
• Mineralization

Adapted from: Barret M., 2009.
Environmental contamination

More than 20,000 WWTP in France:
Each day, around 14 millions m$^3$ of water containing a huge diversity of micropollutants released in the environment

What is the potential impacts of these micropollutants on Human health and aquatic environment?

http://assainissement.developpement-durable.gouv.fr/
Substances selection

European policies
- Monitoring in aquatic environment

Studies with quantification in WWTP effluents

Studies considering emerging contaminants

Water Framework Directive
- French National Action RSDE
- French projects and studies
- Expert assessment of Synteau and INRA

286 substances selected: 261 organic compounds and 25 inorganic compounds
Selected substances

- Pharmaceuticals
- Pesticides
- Inorganic compounds
- PolyChloroBiphenyls
- PolyChloroDibenzo Dioxines and Furanes
- Polycyclic Aromatic Hydrocarbons
- Non classified
- Alkylphenols
- HaloPhenols
- HexaBromoCycloDoDecans
- PolyBromoDiphenylEthers
- BTEX
- Chlorobenzenes
- Organtins
- Halogenated Volatile Organic Compounds

Mainly pharmaceuticals and pesticides

15 families: high variety of compounds ⇔ high variety of fate and toxicity

Number of substances:
- Pharmaceuticals: 87
- Pesticides: 66
- Polycyclic Aromatic Hydrocarbons: 16
- PolyChloroDibenzo Dioxines and Furanes: 17
- PolyChloroBiphenyls: 18
- Inorganic compounds: 25
- Alkylphenols: 8
- HaloPhenols: 8
- HexaBromoCycloDoDecans: 5
- PolyBromoDiphenylEthers: 7
- Organtins: 4
- Chlorobenzenes: 3

15 families contain a high variety of compounds and are often found in the environment.
Calculation

One-year balance

Concentration

\[ \frac{\mu g}{m^3} \]

\[ x \]

Volume

Mass released to aquatic environment

Potential impacts on Human health and aquatic environment

\[ x \text{ characterization factor (USEtox 2.1 \textsuperscript{\textregistered})} \]
Concentrations and annual masses released to aquatic environment

- Data representative of the whole WWTPs
- $C^o < \text{Quantification Limit} = \frac{QL}{2}$
- $\bar{C}^o = \text{geometric mean} + 95\% \text{ confidence interval}$

One-year volume = 5 billion m$^3$

One-year mass = one-year volume $\times$ concentration
Characterization factor

**Reference method in Life Cycle Assessment** for assessing human toxicity and freshwater ecotoxicity

**DALY** = Disability Adjusted Life Years = number of life years « lost » because of illness, handicap or death

**PDF.m^3.j** = Potentially Disappeared Fraction x cubic meter x day = fraction of species potentially disappeared integrated to volume and time

https://www.usetox.org/
Potential impacts calculation

Potential impact = one-year mass x characterization factor

Total impact = \( \sum \) impacts

Organic and inorganic compounds treated separately:

\( \neq \) concentrations  \( \neq \) USEtox 2.1®  \( \neq \) fate

Silva et al. 2002
Available data and selecting

- 261 organics (100%)
  - 225 (86%)
    - 153 (59%)

List

- 25 inorganics (100%)
  - 25 (100%)

Compounds with at least one concentration available

Compounds with more than 10% data > QL

- 24 (96%)

• Selecting allows to eliminate:
  • Non precise data
  • Substances poorly quantified with high QL which overestimate concentration
153 organic micropollutants mass released into aquatic environment

- Concentrations range: 0.1 ng.L\(^{-1}\) to 5 µg.L\(^{-1}\)
- 90% micropollutants: ng.L\(^{-1}\) < C° < µg.L\(^{-1}\)
- Mass range: kg to tons
- \(\sum 153 \approx 150\) tons

- 15/153 micropollutants represent 70% of the mass:
  - 9 pharmaceuticals \(\Leftrightarrow\) 48% of mass:
    - atenolol, carbamazepine, furosemide, sotalol, chlordiazepoxide, hydrochlorothiazide, ranitidine, irbesartan, valsartan
  - 6 other compounds \(\Leftrightarrow\) 22% of mass:
    - tetrachloroethylene, trichloromethane, dichloromethane, NP1EC, DEHP, AMPA
24 inorganic substances mass released into aquatic environment

- Concentrations range: 9 ng.L\(^{-1}\) to 200 µg.L\(^{-1}\)
- 90% micropollutants: 0.1 < C° < 40 µg.L\(^{-1}\)
- Mass range: 10\(^1\) kg to 10\(^3\) tons
- \(\sum 24 \approx 2\,000\,000\) tons

- 5/24 micropollutants represent 85% of the mass:
  - Iron, boron, aluminum, zinc and manganese

- Concentrations and mass in general higher than those of organic micropollutants:
  - Use in wastewater treatment (Fe)
  - Naturally present in water
  - No biodegradation
Available data and selecting

- 261 organics (100%)
  - 225 (86%)
    - 153 (59%)
      - 94 (36%)
      - 88 (34%)
  - 24 (96%)

List

- 25 inorganics (100%)
  - 25 (100%)
    - 24 (96%)

Compounds with at least one concentration available

Compounds with more than 10% data > QL

Human toxicity

- 15 (60%)

Characterized substances

Ecotoxicity

- 19 (76%)

Lack of characterization factors (especially for pharmaceuticals)
Characterization factors

- **Inorganic micropollutants CFs > Organic micropollutants CFs** in general (no biodegradation)
- **Inorganic micropollutants CFs** less precise
- **Fate**: use of mean speciation for inorganic compounds
Potential impacts of micropollutants on Human health

- **9/15** organic micropollutants with highest mass have CFs (atenolol, carbamazepine, furosemide, sotalol, hydrochlorothiazide, tetrachloroethylene, trichloromethane, dichloromethane and DEHP)

- **1/5** inorganic micropollutants with highest mass has CF (Zn)
Potential impacts of micropollutants on Human health

- **9/15 organic micropollutants with highest mass have CFs** (atenolol, carbamazepine, furosemide, sotalol, hydrochlorothiazide, tetrachloroethylene, trichloromethane, dichloromethane and DEHP)

- **1/5 inorganic micropollutants with highest mass has CF** (Zn)
Potential impacts of micropollutants on Human health

• Toxicity is very important when estimating potential impacts

<table>
<thead>
<tr>
<th>Potential impact on Human health (DALY – number of year lost)</th>
<th>94 organic micropollutants</th>
<th>15 inorganic micropollutants</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 (≈ 3 s/year/inhabitant)</td>
<td>818 (≈ 6.4 min/year/inhabitant)</td>
<td></td>
</tr>
</tbody>
</table>

• Potential impacts on Human health low

• No direct exposure (dermal exposure not considered in USEtox ®)

• Drinking water treatment before consumption (ozonation, active carbon)

• Missing CFs for emerging compounds (31/59 pharmaceuticals) and for highly concentrated inorganic micropollutants (iron, aluminium, etc.)
Potential impacts of micropollutants on Aquatic environment

- **8/15** organic micropollutants with highest mass have CFs (sotalol, atenolol, carbamazepine, tetrachloroethylene, dichloromethane, trichloromethane, NP1EC, DEHP,)
- **4/5** inorganic micropollutants with highest mass has CF (iron, aluminum, zinc, manganese)
Potential impacts of micropollutants on Aquatic environment

- **8/15 organic micropollutants with highest mass have CFs** (sotalol, atenolol, carbamazepine, tetrachloroethylene, dichloromethane, trichloromethane, NP1EC, DEHP)

- **4/5 inorganic micropollutants with highest mass have CF** (iron, aluminum, zinc, manganese)
### Potential impacts of micropollutants on Aquatic environment

<table>
<thead>
<tr>
<th></th>
<th>88 organic micropollutants</th>
<th>19 inorganic micropollutants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potential impact on Aquatic</td>
<td>61</td>
<td>2,858</td>
</tr>
<tr>
<td>environment (10^9 PDF.m^3.d)</td>
<td>(∼ 0.1 species potentially disappeared/year)</td>
<td>(∼ 6 species potentially disappeared/year)</td>
</tr>
</tbody>
</table>

- Micropollutants does have an impact on aquatic environment
- WWTP effluents versus other emissions in aquatic environment?
- Not taken into account: antibioresistance, endocrine disruption, cocktail effect, etc.
- Number of studied compounds <<<< number of existing compounds
Conclusions

• Potential impacts:
  • Low on Human health
  • Noticed on Aquatic environment ➔ comparison needed

• Toxicity generally more important than concentration for impacts

• Impacts calculated with 1/3 of selected micropollutants:
  • Lack of concentration data
  • Lack of toxicological and ecotoxicological data

• With our data, possible to estimate impacts linked to micropollutants in WWTP effluents

• Restricted number of substances compared to existing ones

• Restricted knowledge on the effects on Human health and aquatic environment

• Nanomaterials, nanoplastics, resistance genes present in WWTP effluents not taken into account

• Mean data at the scale of France and only additive effects considered
Perspectives

• **Comparison at WWTP scale:**
  - Other emissions (air, sludge)
  - Different treatments (e.g. tertiary treatments)

• **Comparison at catchment basin scale:** emissions from WWTP effluents, agriculture, industries, etc. ➔ **identify the main source of impact**

• **Comparison** of concentrations/masses **with values from other countries** (Europe, United States)

• Toxicity and LCA studies to **obtain missing characterization factors**
Thank you to Synteau for their scientific and financial support...

... and thank you for your attention!

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