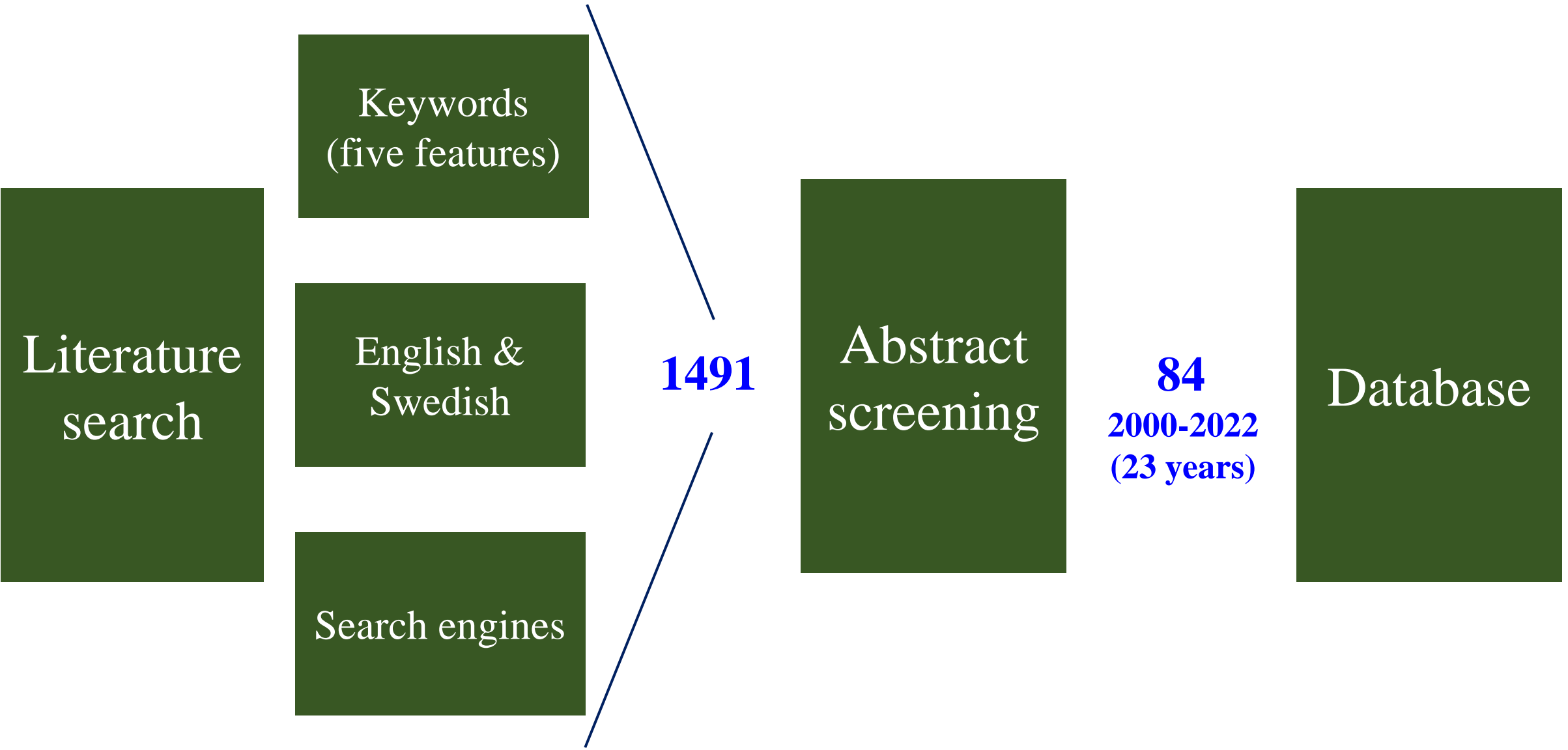


Research questions

- 1. Which chemical pollutants are of high concern, as potential obstacles to sustainable wastewater reuse?*
- 2. To what extent do these pollutants impact on environmental and human health? How can their risks and hazards be assessed?*
- 3. How can advanced treatment techniques help remove these pollutants to enable safer reuse?*
- 4. What are the factors influencing the potential for wastewater reuse across countries?*

Methodology – National literature review and synthesis workflow



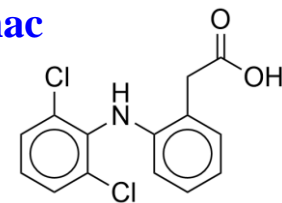
Methodology – Meta-analysis workflow

Database

~ 630 substances

> 20 quantifiable data points (effluent concentrations) > 50% of quantifiable frequency

Diclofenac



~ 160 quantifiable data points
~ 180 total number of entries
93% quantifiable frequency



~130 substances



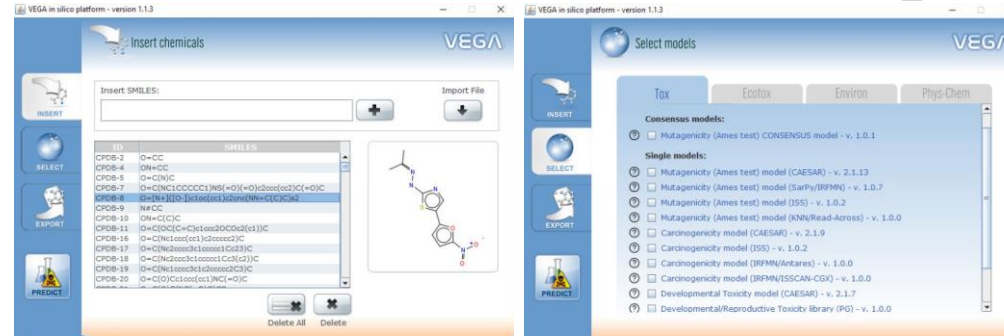
PFDS



2 quantifiable data points
~ 50 total number of entries
4% quantifiable frequency

~15 000 data entries
Swedish effluent wastewater (municipal & domestic settings)

Risk and hazard evaluations of chemicals for effluent water quality



VEGA
By EC-funded LIFE
project CONCERT REACH

Ecological risk assessment

$$\text{Risk quotient (RQ}_{\max}) = \frac{MEC_{eff,max}}{PNEC}$$

$$\text{Risk quotient (RQ}_{95\%tile}) = \frac{MEC_{eff,95\%tile}}{PNEC}$$

$$\text{Frequency of Exceedance (FoE)} = \frac{\text{No. of data points exceeded PNEC}}{\text{Total no. of data points}}$$

PNEC: predicted no effect concentrations for aquatic species (USEPA, ECHA & FASS)

Environmental health hazard

Persistency

Mobility

Bioaccumulation

Human health hazard

Mutagenicity

Carcinogenicity

Estrogen effects

.....

Risk and hazard evaluations of chemicals for effluent water quality



Prioritised
chemical list

- 1) _____
- 2) _____
- 3) _____
- 4) _____
- 5)

Criteria and scoring

Applied practice

Score 1 (RQ>1 = risk)

Score 0 (RQ<1 = no risk)

REACH Guidelines

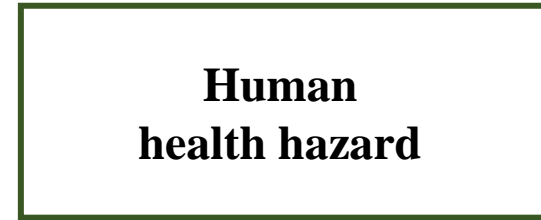
Score 1 (risk)

Score 0 (no risk)

Applied practice

Score 1 (active)

Score 0 (inactive)

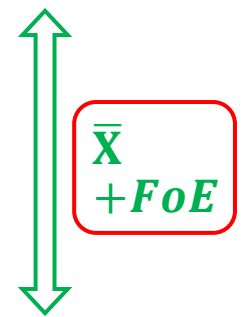


Final score

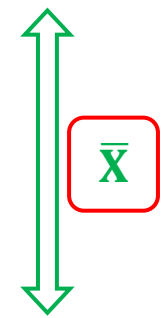
$$\text{Risk quotient (RQ}_{\max}) = \frac{MEC_{eff,max}}{PNEC}$$

$$\text{Risk quotient (RQ}_{95\%tile}) = \frac{MEC_{eff,95\%tile}}{PNEC}$$

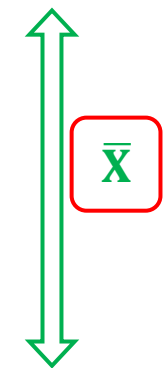
$$\text{Frequency of Exceedance (FoE)} = \frac{\text{No. of data points exceeded PNEC}}{\text{Total no. of data points}}$$



Persistency
Mobility
Bioaccumulation



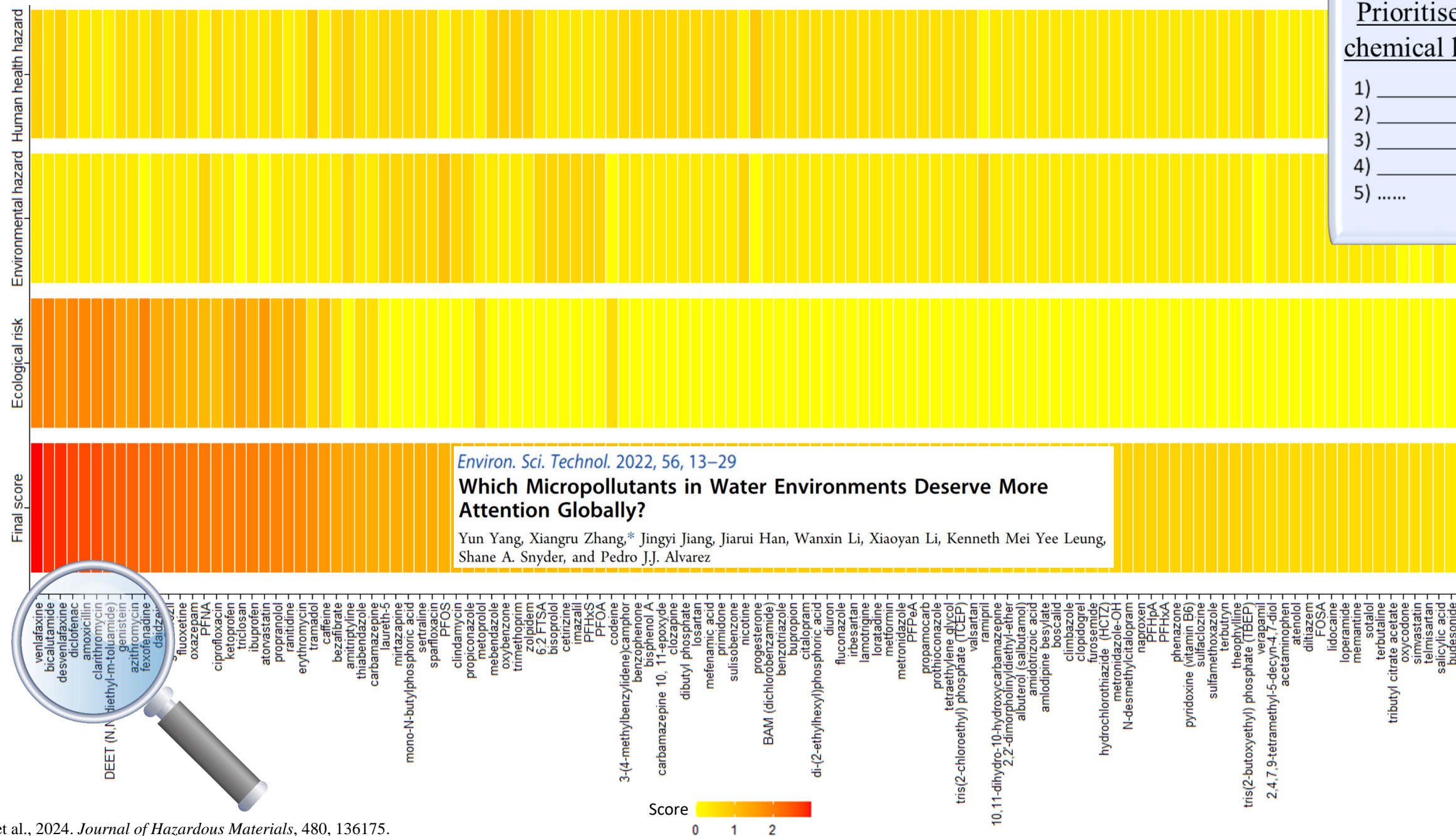
Mutagenicity
Carcinogenicity
Estrogen effects
.....



Prioritised chemicals in effluent wastewater of Sweden

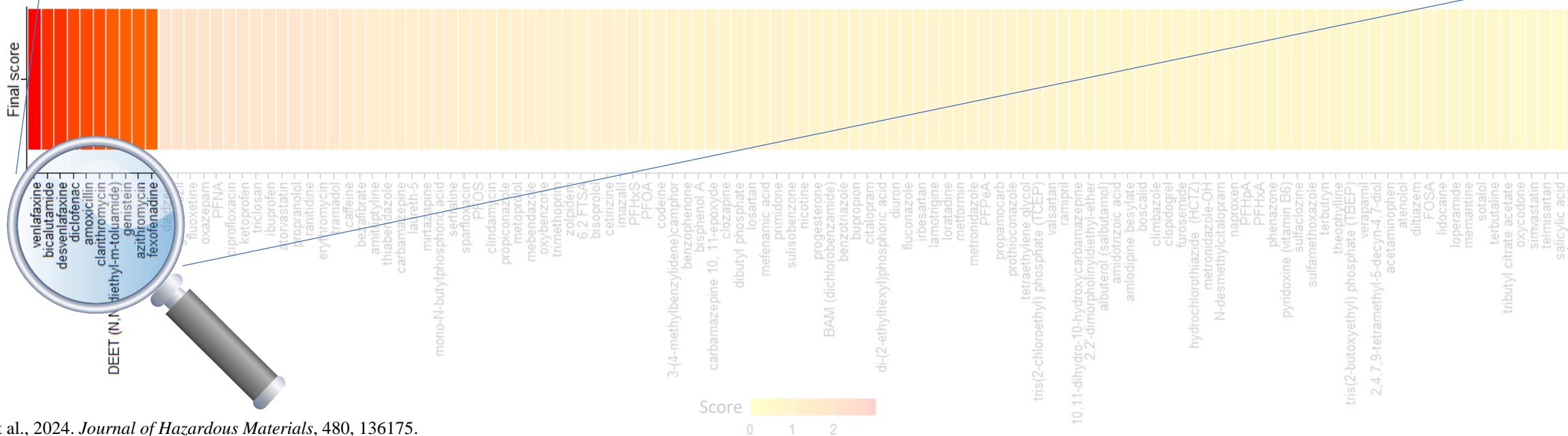
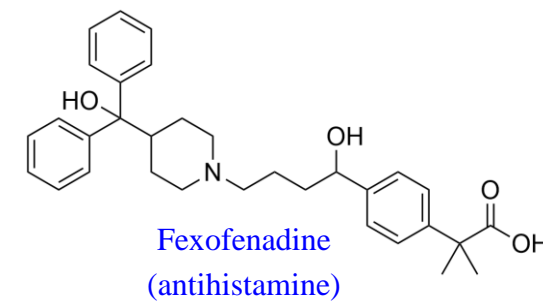
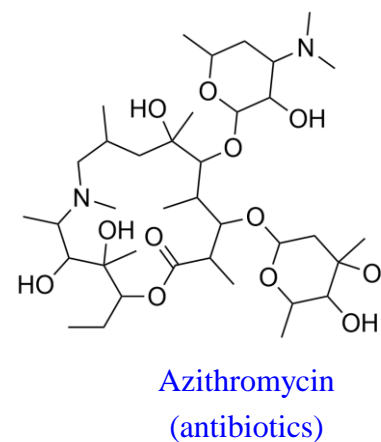
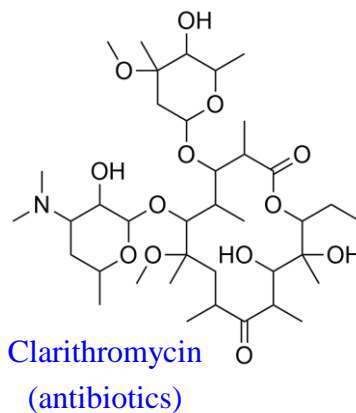
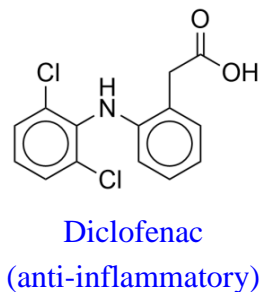
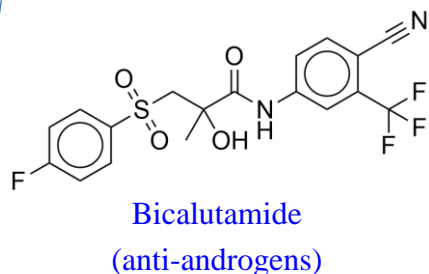
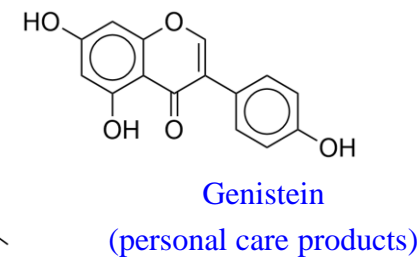
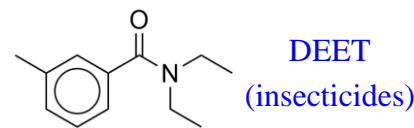
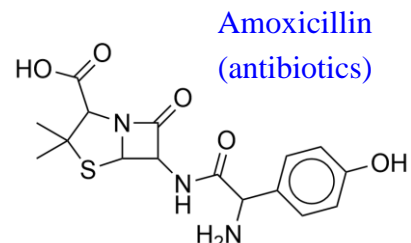
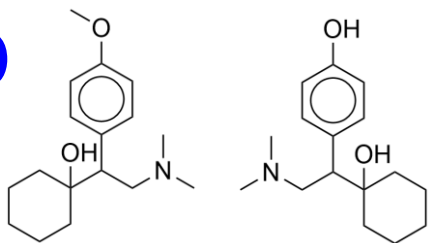
Prioritised chemical list

- 1) _____
- 2) _____
- 3) _____
- 4) _____
- 5)



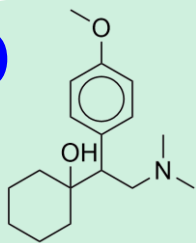
Prioritised chemicals in effluent wastewater of Sweden

Top-10

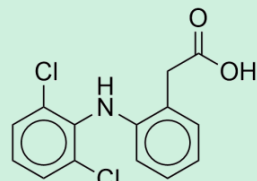


Prioritised chemicals in effluent wastewater of Sweden

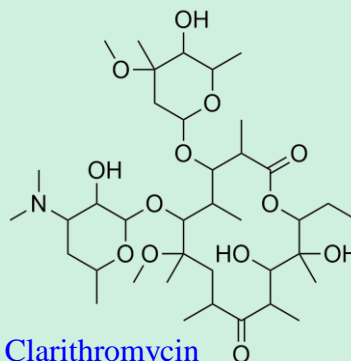
Top-10



Venlafaxine
(antidepressants)

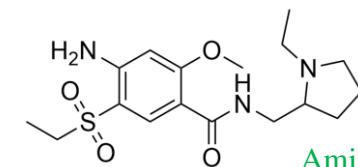


Diclofenac
(anti-inflammatory)

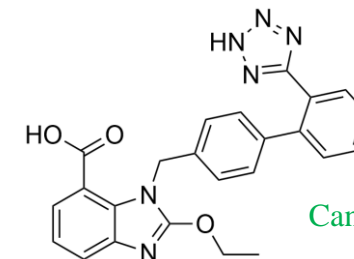


Clarithromycin
(antibiotics)

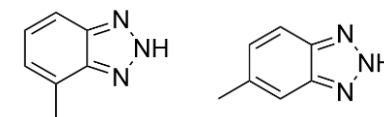
EU UWTD (2024/3019)



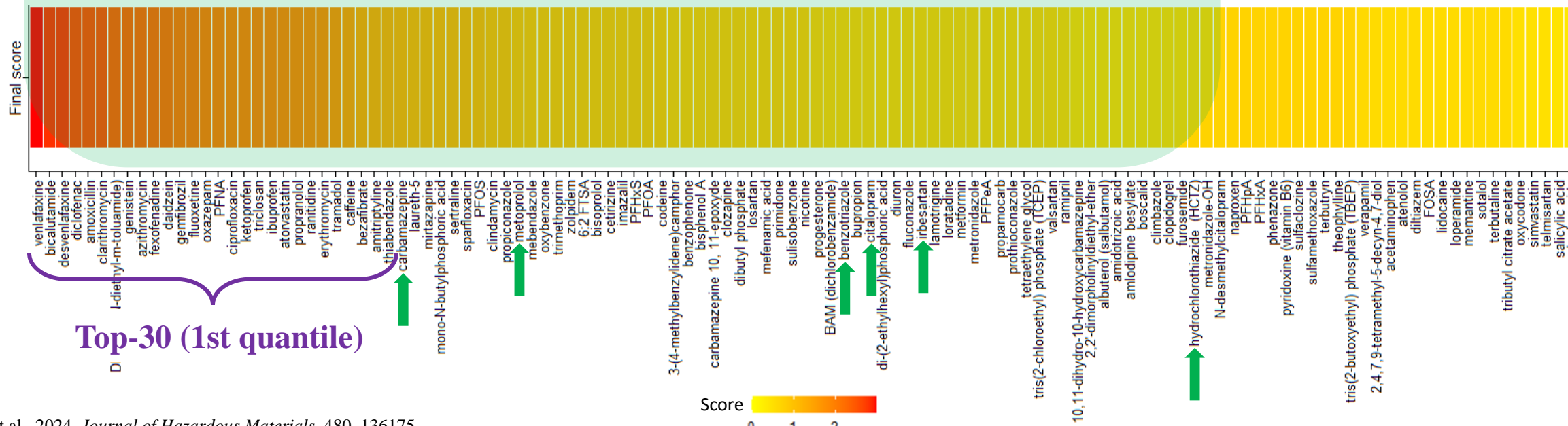
Amisulpride



Candesartan



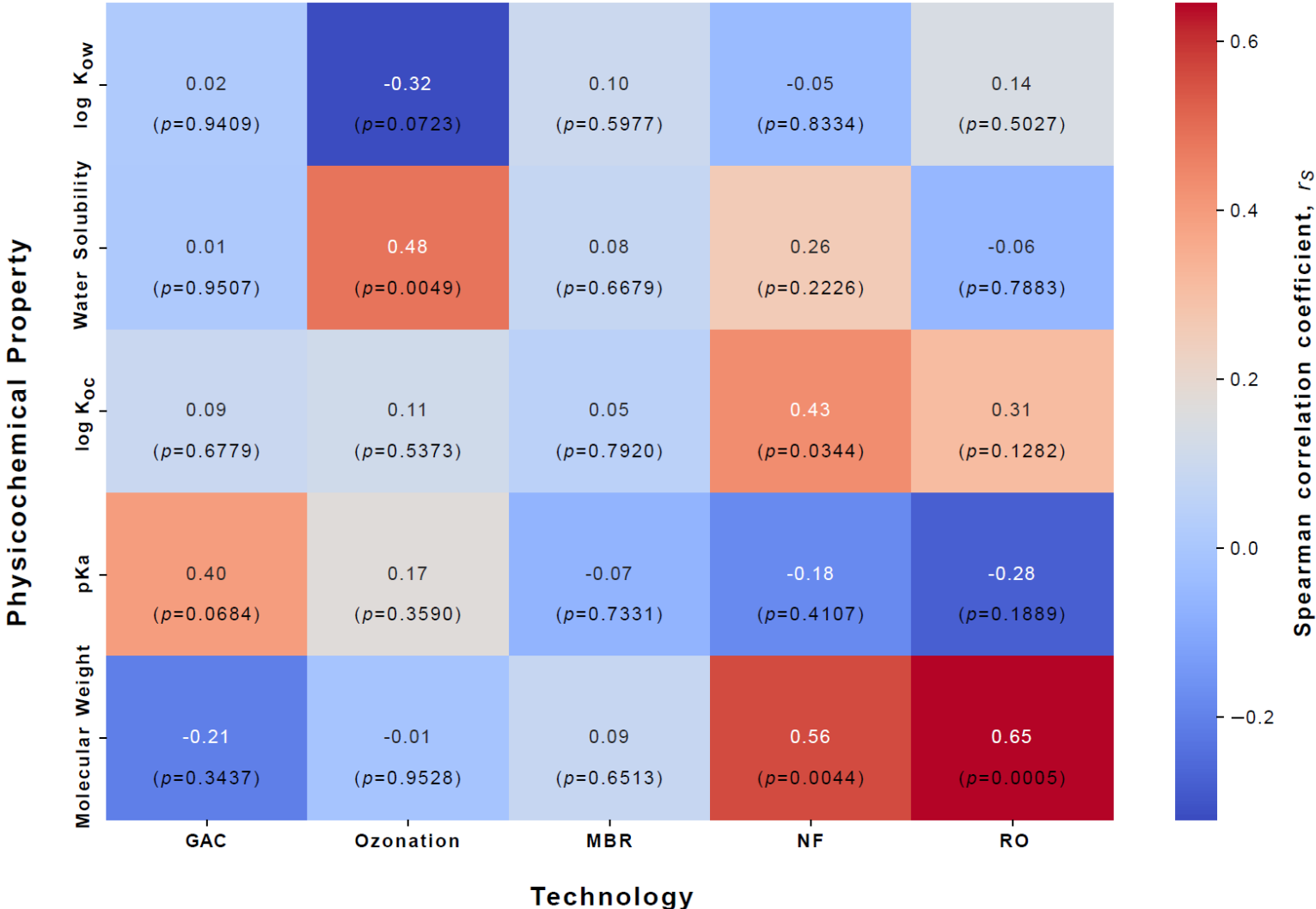
4- or 5-Methylbenzotriazole isomers



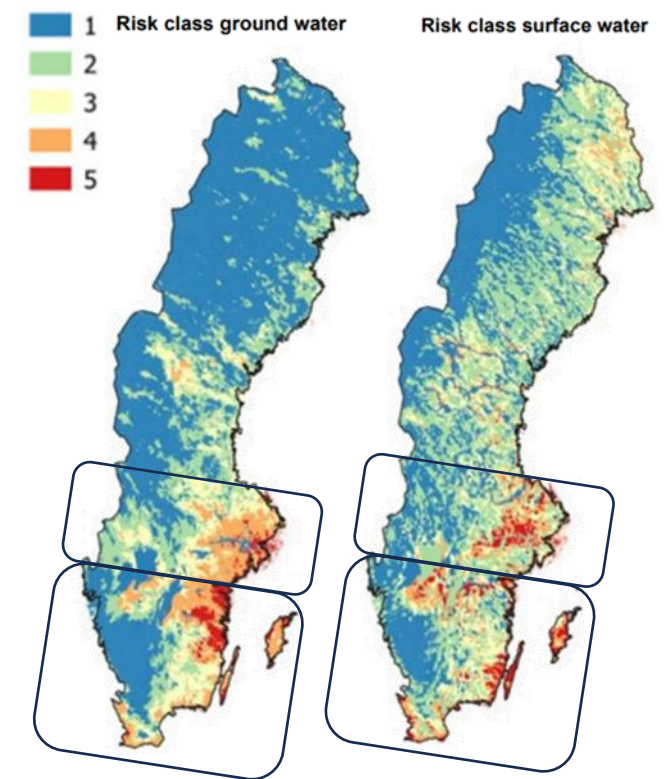
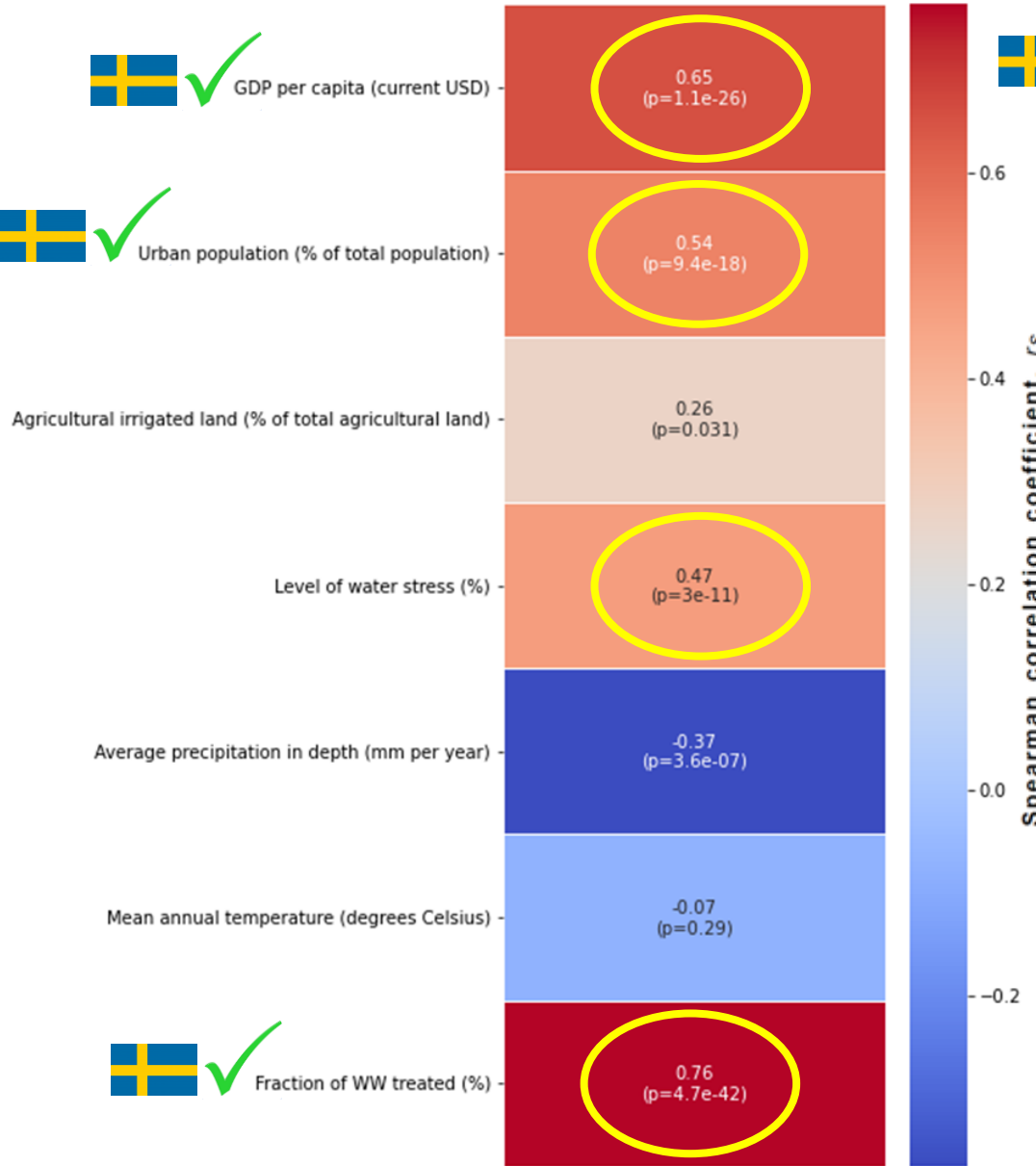
Maximum removal of our priority chemicals (top-30 (Q1)) & EU UWTD by advanced treatment technologies – literature review with international scientific studies (n=56, year 2007–2023)

	GAC	Ozonation	MBR	NF	RO
Average RE (%)	94.0	86.2	65.9	88.1	91.9
Venlafaxine	100.0	96.3	43.0	99.2	99.0
Bicalutamide	No data	40.0	No data	74.0	No data
Desvenlafaxine	No data	No data	64.2	No data	No data
Diclofenac	100.0	100.0	21.0	93.0	100.0
Amoxicillin	No data	No data	80.0	100.0	99.7
Clarithromycin	100.0	100.0	100.0	100.0	99.9
Deet (n,n-diethyl-m-toluamide)	17.2	80.0	27.0	95.0	84.0
Genistein	No data	No data	96.7	100.0	100.0
Azithromycin	98.9	100.0	78.0	99.9	100.0
Fexofenadine	90.0	96.0	45.0	No data	No data
Daidzein	No data	No data	No data	No data	No data
Gemfibrozil	96.9	90.0	95.0	94.0	100.0
Fluoxetine	100.0	100.0	70.0	97.0	99.2
Oxazepam	94.0	83.3	2.3	No data	No data
PFNA	No data	80.9	No data	No data	100.0
Ciprofloxacin	82.3	100.0	71.4	98.1	100.0
Ketoprofen	100.0	99.2	100.0	90.9	15.1
Triclosan	100.0	75.8	98.0	No data	59.2
Ibuprofen	100.0	57.0	90.0	85.7	95.9
Atorvastatin	No data	No data	99.0	93.0	No data
Propranolol	100.0	87.0	65.5	30.0	97.0
Ranitidine	No data	100.0	92.0	98.9	99.0
Erythromycin	100.0	100.0	59.0	100.0	100.0
Tramadol	100.0	100.0	No data	99.6	98.8
Caffeine	99.9	85.0	97.7	74.0	97.8
Bezafibrate	No data	80.0	96.0	93.1	99.5
Amitriptyline	No data	92.0	98.0	98.0	No data
Thiabendazole	No data	100.0	8.0	No data	No data
Carbamazepine	100.0	100.0	13.2	84.0	99.6
Laureth-5	No data	No data	No data	No data	No data
Amisulprid	No data	100.0	No data	No data	No data
Citalopram	90.0	62.0	42.0	99.6	No data
Hydrochlorothiazide (HCTZ)	99.7	99.0	66.3	No data	99.9
Metoprolol	100.0	96.3	40.0	No data	98.7
Benzotriazole	100.0	98.0	97.2	17.0	70.5
Candesartan	No data	82.0	No data	No data	No data
Irbesartan	92.0	39.0	21.3	No data	No data
Methyl benzotriazole	No data	99.0	No data	No data	85.1

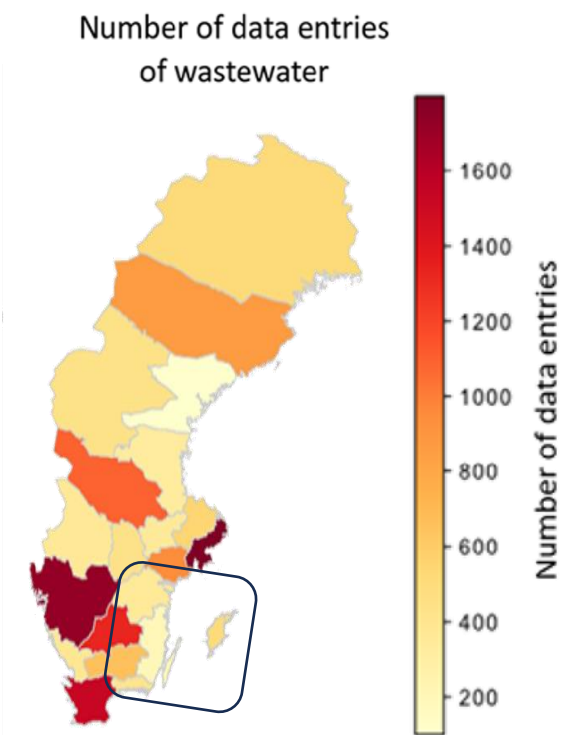
Linking chemical property to their removals in advanced treatment technologies



Factors influencing cross-national differences in wastewater reuse



Stensen K., Krunegård A., Rasmussen K., Matti B. & Hjerdt, N. 2019. Sveriges vattentillgång utifrån perspektivet vattenbrist och torka – Delrapport 1 i regeringsuppdrag om åtgärder för att motverka vattenbrist i ytvattentäkter.



U.A. Khan, P. Löffler, F. Spilsbury, K. Wiberg, C. Stålsby Lundborg & F.Y. Lai. 2024. Towards sustainable water reuse: A critical review and meta-analysis of emerging chemical contaminants with risk-based evaluation, health hazard prediction and prioritization for assessment of effluent water quality. *Journal of Hazardous Materials*, 480, 136175.

Take-home messages and future implications



Policy decisions:

Limiting emissions (\downarrow ecological risk & \uparrow removal)

Water reuse policy (2020/741):

Targets for assessing effluent water quality and for risk management plan

Water technical sectors:

Targets for advanced or quaternary treatments

Research:

Vattnets kreslopp

Allt vatten hänger ihop!



Reference group members

Maximilian Lüdtke, Cezary Bose & Anna Åkerblom (Naturvårdsverket)
Margreta Lundin Unger (HaV)
Anders Finnson (Svenskt Vatten)
Lisa Reiter & Ingrid Bornfeldt Persson (Swedish Board of Agriculture)

Erika Wikdahl & Jessica Lerstorp (Österlen VA)
Shadi El Habash (Region Gotland)
Are Vallin (County Administrative Board of Kalmar)
Andreas Roos (Uddevalla Kommun)

MILJÖ | NATURVÅRDSVERKET
FORSKNING

Att återanvända eller inte: är renat avloppsvatten en giftfri och hållbar resurs för framtiden? (REASSURE)



Risker förknippade med farliga föroreningar vid återanvändning av avloppsvatten och hur de kan minskas

Uzair Akbar Khan, Cecilia Stålsby Lundborg, Lutz Ahrens, Karin Wiberg, Lars Sonesten, Claudia Von Brömssen, Foon Yin Lai

RAPPORT 7173 | DECEMBER 2024

MILJÖ | NATURVÅRDSVERKET
FORSKNING

To reuse or not: is purified wastewater a non-toxic and sustainable resource for the future? (REASSURE)



Risks associated with hazardous pollutants in wastewater reuse and their mitigation

Uzair Akbar Khan, Cecilia Stålsby Lundborg, Lutz Ahrens, Karin Wiberg, Lars Sonesten, Claudia Von Brömssen, Foon Yin Lai

REPORT 7174 | DECEMBER 2024

Journal of Hazardous Materials 400 (2024) 136175

Contents lists available at ScienceDirect

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journal homepage: www.elsevier.com/locate/jhazmat

ELSEVIER

Review

Towards sustainable water reuse: A critical review and meta-analysis of emerging chemical contaminants with risk-based evaluation, health hazard prediction and prioritization for assessment of effluent water quality

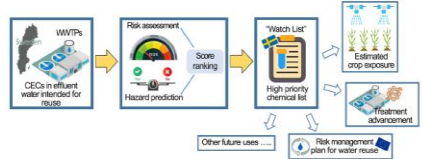
Uzair Akbar Khan^{a,*}, Paul Löffler^b, Francis Spilsbury^b, Karin Wiberg^a, Cecilia Stålsby Lundborg^c, Foon Yin Lai^{a,c}

^a Department of Aquatic Sciences and Assessment, Swedish University of Agricultural Sciences (SLU), SE-75007 Uppsala, Sweden
^b Department of Biological and Environmental Sciences, University of Gothenburg, Carl Skottsbergsgata 22B, 14319 Gothenburg, Sweden
^c Department of Global Public Health, Karolinska Institutet, Tomtebodavägen 18A, 17177, Stockholm, Sweden

HIGHLIGHTS

- Compiled 682 chemicals, metals and (micro)plastics in wastewater intended for reuse.
- New, holistic quantitative methodology to assess, score and prioritize chemical CECs.
- Meta-analysis of chemical CECs with 14 ecological risk and health hazard features.
- List of chemical CECs in high to low priority for evaluating effluent water quality.
- High-priority chemicals are mainly pharmaceuticals with venlafaxine at the very top.

GRAPHICAL ABSTRACT



ARTICLE INFO

Keywords:
Organic micropollutants
Removal efficiency
Wastewater
Irrigation
Environmental pollution
Ecological risk assessment

ABSTRACT

Reuse of treated wastewater is necessary to address water shortages in a changing climate. Sustainability of wastewater reuse requires reducing the environmental impacts of contaminants of emerging concern (CECs), but it is being questioned as CECs are not regulated in the assessment of effluent water quality for reuse both nationally in Sweden and at the broader European Union level. There is also a lack of details in this topic on which CECs to be addressed and methodologies to be used for assessing their environmental impacts. A better understanding of the ecological risks and health hazards of CECs associated with wastewater reuse will assist in the development of effective regulations on water reuse. (Intentionally, as well as related treatment/monitoring guidelines. This review provides a list of specific chemical CECs that hinder sustainable wastewater reuse, and also demonstrates a holistic quantitative methodology for assessing, scoring and prioritizing their associated ecological risks and health hazards posed to the environment and humans. To achieve this, we compile information and concentrations of a wide range of CECs (~15 000 data entries) identified in Swedish effluent wastewater from domestic (blackwater, greywater, mixture of both) and municipal settings, and further perform a meta-analysis of their potentials for 14 risk and hazard features, consisting of ecological risk, environmental hazard, and human health hazard. The features are then scored against defined criteria including guideline

SCIENCE AND EDUCATION
SUSTAINABLE

