Supporting information for "Quantifying variability in removal efficiencies of chemicals in activated sludge wastewater treatment plants – a meta-analytical approach"

Mélanie Douziech[1], Irene Rosique Conesa[1], Ana Benítez-López[1], Antonio Franco[2], Mark Huijbregts[1], Rosalie van Zelm[1]

[1] Department of Environmental Science, Institute for Water and Wetland Research, Radboud University Nijmegen, P.O. Box 9010, 6500 GL, Nijmegen, The Netherlands

[2] Safety & Environmental Assurance Centre, Unilever, Colworth Science Park, Bedfordshire, MK441LQ, UK

Supporting information

60 pages

11 Tables

17 Figures

Content

44

45

S1. Procedure of publication selection

For the fragrances and surfactants, ISI Web of Knowledge, PubMed and Google Scholar were searched. The search was performed between December 2015 and March 2016 using the following combinations: (1) (“fragrance*”) AND (“removal efficiency*” OR “removal*” OR “elimination*” OR “elimination rate*”) AND (“wastewater treatment plant*” OR “WWTP*” OR “sewage treatment plant*” OR “STP*” OR “CAS*” OR “conventional activated sludge*” OR “activated sludge*” OR “conventional wastewater treatment plant*”), (2) (“personal care product*” OR “PCP*”) AND (“removal efficiency*” OR “removal*” OR “elimination*” OR “elimination rate*”) AND (“wastewater treatment plant*” OR “WWTP*” OR “sewage treatment plant*” OR “STP*” OR “CAS*” OR “conventional activated sludge*” OR “activated sludge*” OR “conventional wastewater treatment plant*”), (3) ("anionic surfactant*" OR "non-ionic surfactant*" OR "nonionic surfactant*" OR "cationic surfactant*" OR "amphoteric surfactant*" OR "silicon surfactant*" OR "fluorinated surfactant*" OR " polymeric surfactant*" OR "surfactant polymers*") AND (“removal efficiency*” OR “removal*” OR “elimination*” OR “elimination rate*”) AND (“wastewater treatment plant*” OR “WWTP*” OR “sewage treatment plant*” OR “STP*” OR “CAS*” OR “conventional activated sludge*” OR “activated sludge*” OR “conventional wastewater treatment plant*”). No geographical constraints were applied.

For the pharmaceuticals, the complimentary literature search to the one presented in Lautz, et al. [1] was conducted using the following combinations: (1) “pharmaceuticals” AND “activated sludge” AND (“wastewater” OR “sewage”) AND (“influent” AND “effluent” AND “concentrations”) and (2) “pharmaceuticals” AND “activated sludge” AND (“wastewater” OR “sewage”) AND (“removal efficienc*”). In addition, the following reviews were carefully checked for additional literature: Miege, et al. [2,] Oulton, et al. [3,] Verlicchi, et al. [4].

Figure 1 describes the procedure applied to obtain the final set of publications used for model fitting.

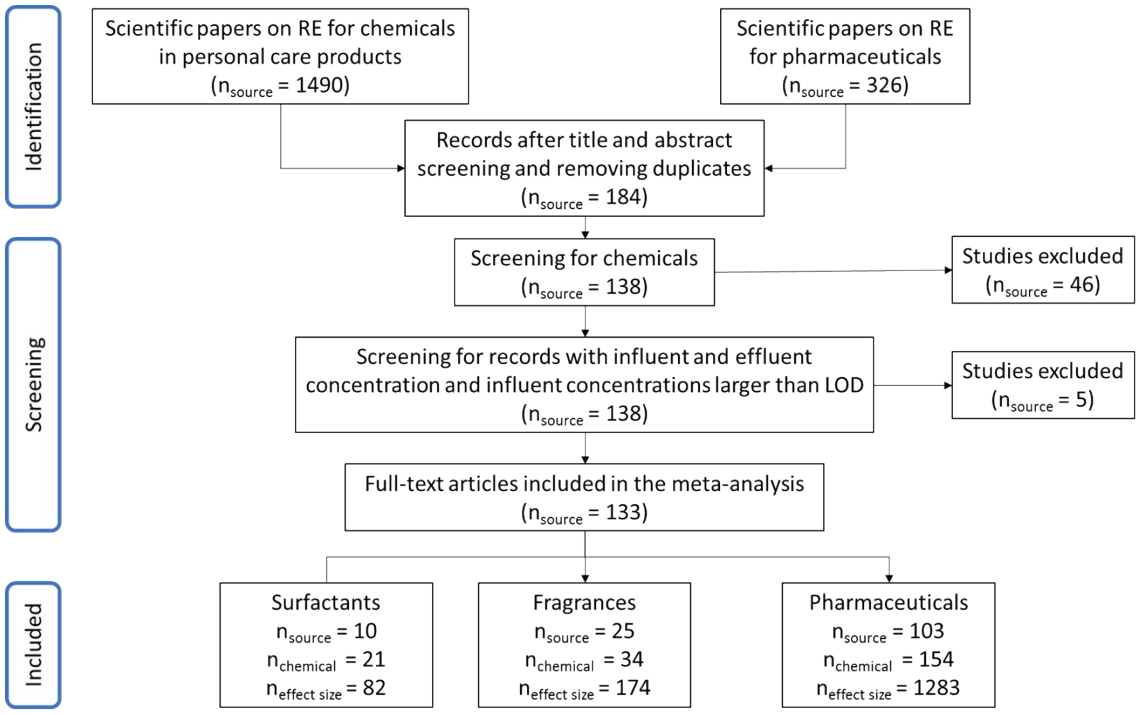

Figure 1 – Flow chart describing the selection of the included studies: n_{source} stands for the number of scientific papers included, $n_{chemical}$ for the number of chemicals, and $n_{effect\ size}$ for the total number of effect sizes computed.

S2. Assumptions for the database creation

a. Effect Size

Different assumptions were necessary to compute the effect sizes for the chosen studies.

Whenever the measured concentrations were below the Limit of Detection (LOD) or below the Limit of Quantification (LOQ), half of the reported LOD or LOQ, respectively, was assigned to this concentration. Concentrations reported as below a certain number were also set to half this reported number. Li and Zhang [5], Johnson, et al. [6], [7] and [8] referred to additional literature for details on the methodology and LOD or LOQ values. Jelic, et al. [9] reported only LOQ, which were assumed to describe the limits for which the chemicals could not be detected. Whenever the LOD was reported as a range, only the maximum value was considered [10].

RE reported as 100% were set to 99.9% [11]. Further, effluent concentrations reported as 0 were set to below detection limits. Effluent concentration reported in ng/g were converted to ug/L assuming a density of water of 1g/mL. Most of the studies reported mean concentrations. Concentrations reported as median were transformed to mean concentrations using the indications in Hozo, et al. [12].
For the following articles, concentrations or standard deviations were derived from graphs using the programme GetData Graph Digitizer v. 2.26.0.20: Belhaj, et al. [13], Bertanza, et al. [14], Duan, et al. [15], Gonzalez, et al. [16], González, et al. [8], Jones, et al. [17], Kanda, et al. [18], Klaschka, et al. [19], Kruglova, et al. [20], Lindqvist, et al. [21], Qi, et al. [22], Ren, et al. [23], Servos, et al. [24], Stumpf, et al. [25], Tauxe-Wuersch, et al. [26], Wang, et al. [27], Yasojima, et al. [28], Zhou, et al. [29].

Concentrations of the same chemical measured at the same WWTP for different days or seasons were averaged to a single mean value.

Gatidou, et al. [30] report suspended and soluble concentrations but since the suspended was in g/kg and no density was given, only the dissolved concentration was considered.

b. Wastewater treatment plant specific parameters

- Hydraulic retention time

Some studies did not mention whether the HRT was for the entire process or just for the aerobic basin. The mean HRT over all the HRTs reported in our database for the entire plant was around 20h, so whenever the reported HRT was below 20h we assumed it was for the aerobic basin only.

The HRT of the aeration basin ($HRT_{aerobic}$) was derived from the total HRT (HRT_{total}) according to equation $HRT_{aerobic} = HRT_{total} - HRT_{PS} - HRT_{FS}$. HRT_{PS} (of the primary settler) and HRT_{FS} (of the final settler) were both assumed to be equal to 2h whenever not given [31].

- Nature influent

In the following, the statements about wastewater composition found in the literature are related to the assumed domestic and industrial wastewater shares. Hereby urban wastewater was assumed to describe domestic wastewater.

  - "mixture of industrial and domestic" without details: 50% domestic, 50% industrial
  - "domestic sewage with seasonal fluctuation due to local viniculture": 90% domestic, 10% industrial
  - "Mainly/mostly domestic/municipal": 90% domestic
  - "municipal wastewater treatment plants" as in Bossi, et al. [32]: 100% domestic
  - "strong influence from textile industry" as in Clara, et al. [33]: 50% domestic, 50% industrial
  - "municipal and industrial and hospital" as in Gomez, et al. [10]: 60% domestic, 20% industrial
  - "urban sewages and some industrial discharges" as in Vallecillos, et al. [34]: 80% domestic, 20% industrial

- Secondary treatment type

The following choices were made to classify the WWTPs in the four categories: plug-flow reactor (PFR), continuously stirred tank reactor (CSTR), oxidation ditch (OD), and sequencing batch reactor (SBR).

  - "Conventional activated sludge process" or "activated sludge" were either classified as PFR or CSTR depending on whether the WWTP implemented biological nutrient removal (BNR) or organic matter removal (OMR).
  - Aerobic/Anoxic/Oxic (A2O) process was classified as PFR
  - Aerobic/Oxic (AO) was classified as PFR

- Conventional SBR was classified as SBR

- Population served

The population served by a WWTP reported in studies was always assumed to be in the unit of person equivalent (PE). In 3.5% of the studies reporting persons served only, the share of industrial influent was larger than 50%. This might have led to an underestimation of the corresponding PE value.

- Design capacity

The design capacity in PE was converted to m^3/d using the mean of the ratio that was available in some studies (Klaschka, et al. [19], Clara, et al. [35], Clara, et al. [36], Solé, et al. [37]), namely around 0.2 m^3/PE. This is comparable to the values found in Ain [38], Benefield [39], Gujer [40]. This was done since more values in m^3/d were available to uniformize how this WWTP design property is reported.

- Additional details on WWTP

For the following studies, the listed literature was used to add some details on the analysed WWTPs.

- Kümmerer, et al. [41]: Abwasserzweckverband Breisgauer Bucht [42]
- Li and Zhang [5]: Kable [43], Kin-ping [44]
- Manickum and John [45]: Umgeni Water Amanzi [46]
- Qi, et al. [22]: chinagate.cn [47]
- Choi, et al. [48]: Seoul Solution [49]
- Golovko, et al. [50]: Hochtief [51]
- Gulkowska, et al. [52]: Kable [43]
- Komesli, et al. [53]: Ankara Metropolitan Municipality [54]
- Bendz, et al. [55]: VASYD [56]
- Bossi, et al. [32]: Miljøministeriet [57]
- Bahlmann, et al. [58]: Berliner Wasserbetriebe [59]
- Solé, et al. [37]: Agència Catalana de l'Aigua [60]

- Sample Type

Whenever the wastewater influent and effluents were sampled as “composite samples” we used the study’s indications to refine the sample type as either flow-proportional, time-proportional, or volume-proportional. We followed indications in Ort, et al. [61] and defined composite samples without further indications as time-proportional.

- Default WWTP design

For the following parameters, the listed default values were used whenever the references did not report any details.

  - Presence of primary settling, secondary treatment, and final sedimentation tank
  - Secondary treatment type: PFR if BNR, CSTR if OMR
  - No tertiary treatment
  - OMR

c. Chemical properties

- Organic carbon-water partitioning coefficient (K_{OC})

The equations listed in Table 1 were used to estimate the K_{OC} according to the chemical's class.

Table 1 – Equations used to estimate the organic carbon-water partitioning coefficient (K_{OC}). K_{OW} stands for the octanol-water partitioning coefficient, Φ_n represents the neutral fraction, and Φ_{ion} the ionised fraction, D_{OW} is the apparent K_{OW} at the actual pH, set to 7.

Class	Equation		Source
Neutral	$\log K_{OC} = 0.1 + 0.81 \cdot \log K_{OW}$	(1)	[62]
Acid	$\log K_{OC} = log(\phi_n \cdot 10^{0.54 \cdot \log K_{OW} + 1.11} + \phi_{ion} \cdot 10^{0.11 \cdot \log K_{OW} + 1.5}$	(2)	[63]
Base	$\log K_{OC} = 0.31 \cdot \log (D_{OW}) + 2.78$	(3)	[64]

- Henry's law constant

EPI Suite [65] was not able to estimate a Henry's law constant for a chemical with vapour pressure = 0. This value was therefore set to 1E-4 Pa*m3/mol to represent non-volatile chemicals.

- Biodegradation

Chemicals were classified (1) as either readily biodegradable or not, and (2) as one of the biodegradability classes from ECETOC [64] (Table 2).

Table 2 – Biodegradability classes as used in the database and determined from the biodegradation rate constant sometimes available for given chemicals.

	Biodegradation rate constant

	[hr^{-1}]
Readily biodegradable	1
Readily biodegradable, failing 10-d window	0.3
Inherently biodegradable, fulfilling specific criteria	0.1
Inherently biodegradable, not fulfilling specific criteria	0
Not biodegradable	0

178

179 • Degradation by-products

180 The following chemicals were not considered, as they were found to be potential degradation by-
181 products of other chemicals.

Chemical	Justification	Source
Alkylphenols and alkylphenol precursors (-carboxilic acids and ethoxylates)	Not possible to isolate the parent chemical	[66]
Perfluorinated surfactants	Could all be degradation products, parent chemical cannot be isolated	[67]
4-Aminoantipyrine	Metabolite from aminopyrine (occurring in the body directly)	[68]
4-Methylaminoantipyrine	Metabolite from aminopyrine (occurring in the body directly)	[68]
Theophylline	A small amount of theophylline is one of the products of caffeine metabolic processing in the liver	[69]
N-acetyl-4-amino-antipiryne	Metabolite from aminopyrine (occurring in the body directly)	[68]
NCI	Active metabolite of the antidepressant drugs	[69]
Estriol	Estrone can be further oxidized to estriol	[70]
Estrone	Oxidation product of estradiol	[70]
Ethinylestradiol	Small portions are formed from mestranol	[70]
Norfluoxetine	Most important active metabolite of fluoxetine	[69]

O-desmethyl venlafaxine	Major urinary metabolite of venlaflaxine	[71]
Seproxetine	Most important active metabolite of fluoxetine	[72]
Aminosalicyclic acid	Amino derivative of salicyclic acid	[69]
Digoxigenin	Metabolite of digoxin	[73]
Desmethylnaproxen	Naproxen metabolite	[74]
4-Hydroxydiclofenac	Diclofenac metabolite	[74]
5-Hydroxydiclofenac	Diclofenac metabolite	[74]
Carboxydiclofenac	Diclofenac metabolite	[74]
Dihydroketoprofen	Ketoprofen metabolite	[74]
Acetamidoantipyrine	Antipyrine metabolite	[68]
Oestrone	Oxidation product of estradiol	[70]
Oxazepam	Metabolite of diazepam, prazepam, and temazepam	[69]
Carbamazepine-10.11-epoxide	Transformation product of carbamazepine	[75]
10-hydroxy-carbamazepine	Transformation product of carbamazepine	[75]
DiOH-Cbz	Transformation product of carbamazepine	[75]
2-hydroxy-carbamazepine	Transformation product of carbamazepine	[75]
Acridone	Scaffold of some synthetic chemicals	[69]
Modafinil Acid	Major metabolite of modafinil	[69]
Norquetiapine	Active metabolite of antipsychotic drug	[76]
Temazepam	One of diazepam's primary active metabolites	[69]
NCL	Major active metabolite of the atypicalantipsychotic drug clozapine	[69]
N4-Acetylsulfamethoxazole	Degradation from sulfamethoxazole	[75]
Dehydronifedipine	Metabolite of nifedipine	[77]
Desmethydiltiazem	Metabolite of Diltiazem	[69]
10-Hydroxy-amitriptyline	Amitriptyline metabolite	[78]
Norverapamil	Main active metabolite of verapamil	[69]
4-Epitetracycline	Epimer of the antibiotic tetracycline	[79]

Androstenedione	Pro hormone of testosterone	[69]

- Linear alkylbenzene sulfonate (LAS)

In the following list, the studies reporting LAS concentrations are listed together with their definition of the LAS chemical. Whenever weight percentages were given, this was used to compute weighted averages of the physico-chemical properties of the group. When no details were given, the physico-chemical properties were computed as weighted averages using the average chain length.

- Clara, et al. [33]: C10LAS
- Feijtel, et al. [80,] Li, et al. [81,] Sabaliunas, et al. [82,] and Holt, et al. [83] did not specify which LAS species they considered, so C12LAS was used as default.
- Gomez, et al. [84] and Gonzalez, et al. [16] reported LAS as the sum(C10LAS to C13LAS)
- González, et al. [8] reported LAS as consisting of the following weight percentages: C10: 3.9%, C11: 37.4%, C12:35.4%, C13: 23.1%.
- Gori, et al. [85] reported LAS as consisting of the following weight percentages C10: 3.9%; C11: 37.4%; C12: 35.6%; C13:23.1%.
- Pirsaheb, et al. [86] mention the definition of LAS (Commercial LAS is composed of isomers and homologs, each containing an aromatic sulfonated ring attached to a linear alkyl chain consisting of 10–14 carbon atoms) so that it was assumed they considered the group of C10LAS to C14LAS.
- Further, studies reporting LAS with average chain length of 11.89 or 11.91 were assigned the physicochemical properties of C12LAS.

S3. Final Database

a. Geographical coverage

Figure 2 shows the spatial distribution of the studies included in the final database.

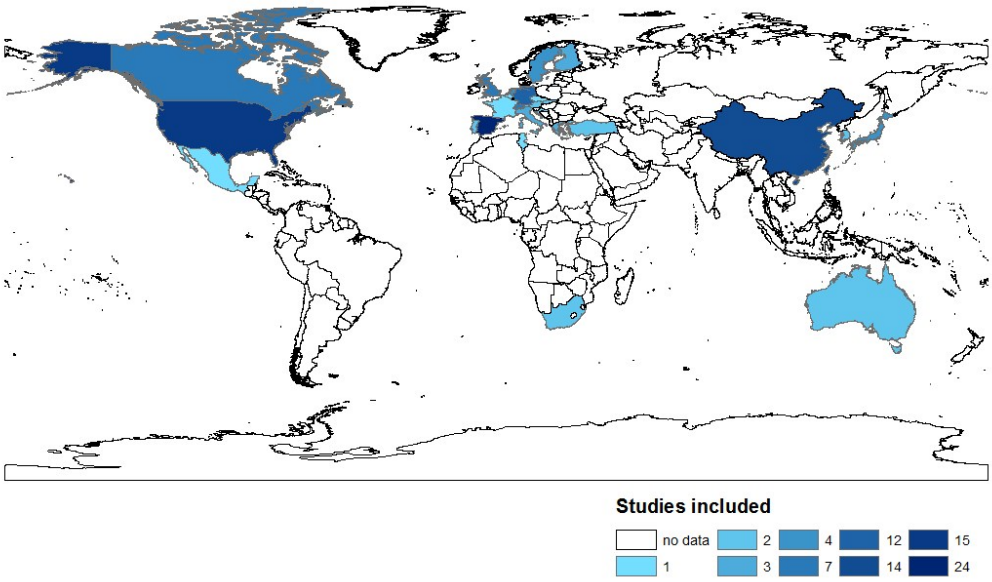

Figure 2 – Spatial distribution of the studies included in the final database

b. Chemicals included

Table 3 lists all the chemicals included in the raw database (n=1539).

Table 3 – Chemicals included in the raw database (n=1539).Type stands either for fragrances (FR), surfactants (SU) or pharmaceuticals (P). Class describes whether the compound is neutral (N), acid (A), or basic (B). The physico-chemical properties are then described together with an indication whether the values are experimental (Exp? Yes) or not. The last column finally describes whether the chemical was in the final database (n=542) to which the mixed-effect model was fitted.

Name	Type	Class	pKa		log KOC		log HC		Readily biodegradable?		In final database?
			Value	Exp.?	Value	Exp.?	Value	Exp.?	Value	Exp.?	
Acetyl cedrene	FR	N		no	4.8	no	1.5E+01	no	no	no	
ADBI	FR	N		yes	5.0	no	2.1E+01	no	no	no	yes
AHDI	FR	N		no	4.9	no	1.9E+01	no	no	no	yes
AHMI	FR	N		yes	5.5	no	1.9E+01	no	no	no	yes
AHTN	FR	N		no	4.8	yes	2.1E+01	yes	no	yes	yes
Ambrettolide	FR	N		no	4.6	no	1.3E+00	no	yes	no	
ATII	FR	N		no	5.7	no	2.7E+01	no	no	no	yes
Benzyl acetate	FR	N		no	1.7	no	1.1E+00	yes	yes	yes	
Benzyl salicylate	FR	A	8.11	no	3.8	yes	2.2E-02	no	yes	yes	
Civetone	FR	N		no	5.3	no	1.2E+02	no	no	no	
DPMI	FR	N		no	4.5	no	1.9E+01	no	no	no	yes
Eugenol	FR	N	10.19	yes	1.9	no	2.0E-01	yes	yes	yes	
Exaltolide	FR	N		no	4.7	yes	1.1E+01	no	yes	yes	
Exaltone	FR	N		no	4.8	no	2.1E+01	no	no	no	
g-methyl ionone	FR	N		no	3.9	no	9.0E+01	no	no	yes	
Habanolide	FR	N		no	4.2	no	9.0E-01	no	yes	no	
Hexyl salicylate	FR	A	8.17	no	4.1	no	1.2E-01	no	yes	yes	
Hexylcinmaldehyde	FR	N		no	4.0	no	5.6E+00	no	yes	no	
HHCB	FR	N		no	4.9	yes	2.4E+01	yes	no	yes	yes
Isobornyl acetate	FR	N		no	3.6	no	2.9E+02	no	yes	yes	

Lilial	FR	N		no	3.7	yes	2.5E+00	yes	yes	yes	
Limonene	FR	N		no	3.7	no	3.2E+03	yes	yes	yes	
Linalool	FR	N		no	2.5	no	2.2E+00	yes	yes	yes	
MA	FR	N		no	3.3	no	2.2E-01	no	no	no	yes
MC4	FR	N		no	3.3	yes	1.5E-02	no	yes	no	
Methyl dihydrojasmote	FR	N		no	2.4	no	1.0E-04	yes	yes	yes	
Methyl salicylate	FR	A	9.80	yes	2.5	no	7.4E+00	yes	yes	yes	
MK	FR	N		no	3.2	no	2.0E-02	no	no	yes	yes
MM	FR	N		no	4.5	no	5.6E-01	no	no	no	yes
Muscone	FR	N		no	5.2	no	6.7E+01	no	no	no	
Musk NN	FR	N		no	3.6	no	9.2E-03	no	yes	yes	
MX	FR	N		no	3.7	no	3.1E-02	no	no	yes	yes
OTNE	FR	N		no	4.7	no	3.2E+01	no	no	no	
Terpineol	FR	N		no	2.5	no	1.2E+00	yes	yes	yes	
Acebutolol	P	B	9.40	no	2.6	no	1.0E-04	no	no	no	yes
Acipimox	P	A	2.80	no	1.4	no	1.0E-04	no	yes	no	
Alprazolam	P	N		no	3.3	yes	1.0E-04	no	no	no	
Alprenolol	P	B	9.43	no	3.0	no	1.0E-04	no	no	no	
Amantadine	P	B	10.76	no	2.3	no	1.3E-02	no	no	no	yes
Amisulpride	P	B	9.37	yes	2.4	no	1.0E-04	no	no	no	
Amitriptyline	P	B	9.40	yes	3.8	yes	1.6E-02	no	no	no	yes
Amphetamine	P	B	10.10	yes	2.4	no	2.0E-01	no	no	no	
Ampicillin	P	A	2.50	yes	1.6	no	1.0E-04	no	no	yes	
Androsterone	P	N		no	3.1	yes	1.0E-04	no	no	no	
Antipyrine	P	N	1.40	yes	0.3	no	2.9E-04	no	no	no	yes
Aspirin	P	A	3.49	yes	1.7	no	3.0E-04	no	yes	no	yes
Atenolol	P	B	9.60	yes	2.3	yes	1.0E-04	no	no	yes	yes
Atorvastatin	P	A	4.30	yes	2.5	yes	1.0E-04	no	no	no	yes
Betaxolol	P	B	9.40	yes	2.8	no	1.0E-04	no	yes	yes	yes
Bezafibrate	P	A	3.60	yes	1.9	no	1.0E-04	no	no	yes	yes
Bisoprolol	P	B	9.27	yes	2.3	yes	1.0E-04	no	no	yes	yes

Bupropion	P	B	8.22	yes	2.5	yes	7.5E-02	no	no	no	yes
Carbamazepine	P	N		no	2.1	yes	1.6E-04	no	no	yes	yes
Carisoprodol	P	N		no	1.8	no	5.2E-02	no	no	no	yes
Cefaclor	P	A	6.84	no	1.4	no	1.0E-04	no	no	no	yes
Cefalexin	P	A	4.50	yes	1.6	no	1.0E-04	no	yes	yes	yes
Celiprolol	P	B	9.50	no	2.5	yes	1.0E-04	no	no	yes	yes
Cetirizine	P	A	6.71	no	2.3	no	1.0E-04	no	no	no	
Chloramphenicol	P	N		no	0.8	no	1.0E-04	no	no	no	
Chlorazepate	P	A	3.43	no	1.9	no	1.0E-04	no	no	no	
Cimetidine	P	B	6.80	yes	2.9	no	1.0E-04	no	no	no	yes
Citalopram	P	B	9.57	no	3.1	no	1.6E-04	no	no	yes	yes
Clarithromycin	P	B	8.99	yes	2.8	yes	1.0E-04	no	no	yes	yes
Clindamycin	P	B	8.73	no	2.8	no	1.0E-04	no	no	no	yes
Clofibric acid	P	A	3.18	no	1.2	yes	3.7E-03	no	no	yes	yes
Clopidogrel	P	B	4.56	no	3.6	no	2.4E-04	no	no	no	
Clozapine	P	NA	7.50	yes	3.5	yes	1.0E-04	no	no	no	
Codeine	P	B	8.21	yes	1.7	yes	1.0E-04	no	yes	yes	yes
Crotamiton	P	N		no	2.4	no	6.8E-02	no	no	no	yes
Dexamethasone	P	N		no	1.4	no	1.0E-04	no	no	no	yes
Dextropropoxyphene	P	B	9.20	no	3.4	no	4.7E-03	no	no	no	
Diatrizoate	P	A	0.92	no	1.9	no	1.0E-04	no	no	yes	yes
Diatrizoic	P	A	0.92	no	1.9	no	1.0E-04	no	no	no	
Diazepam	P	N	3.40	yes	2.6	yes	1.0E-04	no	no	yes	yes
Diclofenac	P	A	4.15	yes	2.4	yes	5.4E-04	no	no	yes	yes
Diethylstilbestrol	P	N		no	3.4	no	1.0E-04	no	no	no	
Diltiazem	P	B	8.06	yes	3.3	no	1.0E-04	no	no	yes	yes
Diphenhydramine	P	B	8.98	yes	3.2	no	5.4E-04	no	yes	yes	
Doxepin	P	B	9.19	no	2.8	yes	2.6E-01	no	no	yes	yes
Enalapril	P	A	2.97	yes	1.7	no	1.0E-04	no	no	no	yes
Eprosartan	P	NA		no	2.2	yes	1.0E-04	no	no	no	
Erythromycin	P	B	8.80	yes	2.8	yes	1.0E-04	no	no	yes	yes

Estradiol	P	N		no	3.2	yes	1.0E-04	no	yes	yes	yes
Etofenamate	P	N		no	3.6	no	6.6E-04	no	no	no	
Famotidine	P	B	7.93	no	2.3	no	1.0E-04	no	no	no	yes
Fenofibrate	P	N		no	4.4	no	1.5E-01	no	no	no	
Fenoprofen	P	A	4.50	yes	2.0	no	2.5E-02	no	no	yes	yes
Fexofenadine	P	NA		no	3.0	yes	1.0E-04	no	no	no	
Fluconazole	P	N		no	0.5	no	1.0E-04	no	no	no	
Fluoxetine	P	B	10.05	no	4.2	yes	1.7E-02	no	yes	yes	yes
Fluvoxamine	P	B	9.39	no	3.0	no	3.6E-02	no	no	no	yes
Gabapentin	P	B	3.68	yes	2.8	no	1.0E-04	no	no	yes	yes
Gemfibrozil	P	A	4.75	no	2.3	no	2.1E-01	no	no	yes	yes
Glibenclamide	P	A	5.19	no	3.5	yes	1.0E-04	no	no	no	yes
Hydroxyzine	P	B	6.62	no	3.3	yes	1.0E-04	no	no	no	
Ibuprofen	P	A	5.06	yes	2.5	yes	1.2E-01	no	yes	yes	yes
Ifosfamide	P	N		no	0.5	no	7.5E-04	no	no	no	
Indapamide	P	A	8.80	yes	2.3	no	1.0E-04	no	no	no	
Indomethacin	P	A	4.50	yes	2.8	yes	1.0E-04	no	no	yes	yes
Iohexol	P	N		no	-1.3	no	1.0E-04	no	no	yes	yes
Iomeprol	P	N		no	-2.2	no	1.0E-04	no	no	yes	yes
Iopamidol	P	N	10.70	yes	-1.9	no	1.0E-04	no	no	yes	yes
Iopromide	P	N		no	-1.6	no	1.0E-04	no	no	yes	yes
Ioxitalamic acid	P	A	0.85	no	1.4	no	1.0E-04	no	no	yes	
Irbesartan	P	A	4.24	no	3.4	yes	1.0E-04	no	no	no	yes
Isradipine	P	N		no	3.0	no	1.0E-04	no	no	no	
Ketoprofen	P	A	4.45	yes	2.0	no	4.1E-04	no	no	yes	yes
Ketorolac	P	A	3.49	yes	1.8	no	1.0E-04	no	no	no	
Lamotrigine	P	B	5.39	no	3.3	no	1.0E-04	no	no	no	yes
Levamisole	P	B	9.99	no	2.5	no	2.7E-03	no	no	no	yes
Levetiracetam	P	N		no	-0.4	no	1.0E-04	no	no	no	
Lincomycin	P	B	7.60	yes	2.7	no	1.0E-04	no	no	no	yes
Loratidine	P	B	4.27	no	4.4	no	4.2E-02	no	no	no	yes

Lorazepam	P	N	13.00	yes	2.5	no	1.0E-04	no	no	no	yes
Meclozine	P	B	6.74	no	4.5	no	1.4E+02	no	no	no	
Mefenamic acid	P	A	4.20	yes	2.4	no	1.7E-03	no	no	no	yes
Melperone	P	B	9.34	no	3.1	no	7.1E-02	no	no	no	
Memantine	P	B	10.79	no	2.7	no	5.1E-03	no	no	no	
Meprobamate	P	N		no	0.7	no	2.6E-03	no	no	no	yes
Mestranol	P	N		no	3.8	no	1.2E-04	no	no	no	
Metformin	P	B	12.40	yes	1.0	no	1.0E-04	no	yes	yes	yes
Methadone	P	B	8.94	yes	2.5	yes	9.5E-04	no	no	yes	yes
Methylprednisolone	P	N		no	1.3	no	1.0E-04	no	no	no	yes
Metoprolol	P	B	9.43	no	2.1	yes	1.0E-04	no	no	yes	yes
Metronidazole	P	N	2.38	yes	1.6	yes	1.0E-04	no	no	no	yes
Miconazole	P	B	6.64	no	4.6	no	8.8E-04	no	no	no	yes
Mirtazapine	P	B	8.10	no	3.3	no	1.0E-03	no	no	no	yes
Modafinil	P	N		no	0.6	no	1.0E-04	no	no	no	yes
Monensin	P	A	6.60	yes	3.0	no	1.0E-04	no	no	no	yes
Morphine	P	NA	8.21	yes	1.7	yes	1.0E-04	no	no	no	yes
Moxifloxacin	P	B	6.43	no	3.6	no	1.0E-04	no	no	no	yes
Nadolol	P	B	9.67	yes	2.2	no	1.0E-04	no	no	no	yes
Nalidixic acid	P	A	8.60	yes	2.0	no	1.0E-04	no	no	no	
Naproxen	P	A	4.15	yes	2.4	yes	2.7E-04	no	yes	yes	yes
Nifedipine	P	N		no	1.9	yes	1.0E-04	no	no	no	yes
Nimesulide	P	A	5.93	no	2.3	yes	1.0E-04	no	no	no	
Nortriptyline	P	B	10.10	yes	3.3	yes	3.5E-02	no	no	no	yes
Omeprazole	P	NA		no	2.4	yes	1.0E-04	no	no	no	yes
Oxcarbazepine	P	N		no	1.3	no	1.0E-04	no	no	no	
Oxycodone	P	B	7.57	no	1.7	yes	1.0E-04	no	no	no	yes
Paracetamol	P	A	9.38	yes	1.8	yes	1.0E-04	yes	yes	yes	yes
Paroxetine	P	B	9.60	yes	4.3	yes	1.0E-04	no	no	no	yes
Penicillin V	P	A	2.79	yes	1.7	no	1.0E-04	no	no	no	yes
Phenobarbital	P	A	7.30	yes	1.9	no	1.0E-04	no	no	no	yes

Piroxicam	P	A	6.30	yes	2.4	no	1.0E-04	no	no	no	yes
Pravastatin	P	A	4.20	yes	1.7	no	1.0E-04	no	yes	no	yes
Prednisolone	P	N		no	1.2	no	1.0E-04	no	no	yes	yes
Prednisone	P	N		no	0.9	no	1.0E-04	no	no	no	yes
Pregabalin	P	B	4.20	yes	2.8	no	1.0E-04	no	yes	no	yes
Primidone	P	N		no	1.4	yes	1.0E-04	no	no	no	yes
Progesterone	P	N		no	3.4	yes	2.3E-02	no	no	no	yes
Propafenone	P	B	9.31	no	3.1	no	1.0E-04	no	no	no	
Propranolol	P	B	9.42	yes	3.0	yes	1.0E-04	no	no	yes	yes
Propyphenazone	P	N		no	1.6	no	4.8E-04	no	no	yes	yes
Ramipril	P	A	5.44	no	2.4	no	1.0E-04	no	no	no	
Ranitidine	P	B	8.36	no	2.7	no	1.0E-04	no	no	yes	yes
Rosuvastatin	P	A	4.25	no	1.7	no	1.0E-04	no	no	no	
Roxithromycin	P	B	8.16	no	2.9	no	1.0E-04	no	yes	yes	yes
Salbutamol	P	NA	10.30	yes	1.5	yes	1.0E-04	no	no	yes	yes
Salicylic acid	P	A	2.97	yes	1.9	yes	1.5E-04	no	no	yes	yes
Sertraline	P	B	9.47	no	4.2	yes	1.4E-02	no	no	no	yes
Sildenafil	P	B	5.99	no	3.5	no	1.0E-04	no	no	no	
Simvastatin	P	N		no	3.6	yes	1.0E-04	no	no	no	
Sotalol	P	NA	8.30	yes	2.4	yes	1.0E-04	no	no	yes	yes
Sulfachloropyridazine	P	A	5.90	no	1.7	no	1.0E-04	no	no	no	
Sulfadiazine	P	A	6.36	yes	1.2	no	1.0E-04	no	no	yes	yes
Sulfamethazine	P	A	7.50	yes	1.9	yes	1.0E-04	no	no	no	yes
Sulfamethoxazole	P	A	3.65	yes	2.0	yes	1.0E-04	no	no	yes	yes
Sulfapyridine	P	A	8.43	yes	1.6	no	1.0E-04	no	no	no	
Sulfathiazole	P	A	7.15	yes	2.2	yes	1.0E-04	no	no	no	yes
Talinolol	P	B	9.53	no	3.0	no	1.0E-04	no	no	no	
Telmisartan	P	A	5.00	no	4.4	no	1.0E-04	no	no	no	
Tenoxicam	P	A	4.50	no	1.7	no	1.0E-04	no	no	no	yes
Testosterone	P	N		no	2.5	yes	1.0E-04	no	no	no	yes
Thiabendazole	P	N	4.64	yes	2.0	no	1.0E-04	yes	no	no	yes

Timolol	P	B	9.21	yes	2.6	no	1.0E-04	no	no	no	yes
Topiramate	P	A	9.22	no	0.7	no	1.0E-04	no	no	no	
Torasemide	P	A	7.10	yes	2.6	no	1.0E-04	no	no	no	
Tramadol	P	B	9.41	yes	2.2	yes	1.0E-04	no	no	yes	yes
Trazodone	P	B	7.52	no	3.6	no	1.0E-04	no	no	no	yes
Triamterene	P	B	6.19	no	3.1	no	1.0E-04	no	no	no	
Triclocarban	P	N		no	4.2	no	1.0E-04	yes	no	yes	yes
Trimethoprim	P	B	6.86	yes	2.8	yes	1.0E-04	no	no	yes	yes
Tylosin	P	B	7.73	yes	3.6	yes	1.0E-04	no	no	no	yes
Venlafaxine	P	B	9.40	yes	2.4	yes	1.0E-04	no	no	yes	yes
Verapamil	P	B	8.92	yes	3.3	yes	1.0E-04	no	no	no	yes
Warfarin	P	A	5.08	yes	2.0	yes	1.0E-04	no	no	no	yes
Xylazine	P	B	7.67	no	2.8	no	1.1E-01	no	no	no	yes
?C12EOS	SU	N		no	1.6	no	1.0E-04	no	yes	no	
?C14EOS	SU	N		no	1.8	no	1.0E-04	no	yes	no	
C10LAS	SU	N		yes	1.8	no	1.0E-04	no	yes	no	
C11LAS	SU	N		yes	1.8	no	1.0E-04	no	yes	no	
C12EO	SU	N		no	1.5	no	2.5E+01	no	no	no	
C12EO1S	SU	N		yes	1.7	no	1.0E-04	no	yes	yes	
C12EO2S	SU	N		yes	1.5	no	1.0E-04	yes	yes	yes	
C12EO3S	SU	N		yes	1.6	no	1.0E-04	no	yes	yes	
C12EO4S	SU	N		yes	1.6	no	1.0E-04	no	yes	yes	
C12EO5S	SU	N		yes	1.6	no	1.0E-04	no	yes	yes	
C12LAS	SU	N		yes	2.6	yes	6.0E-03	yes	yes	yes	
C13LAS	SU	N		yes	1.8	no	1.0E-04	no	yes	no	
C14EO	SU	N		no	2.2	no	1.3E-01	no	no	no	
C14EO1S	SU	N		yes	1.8	no	1.0E-04	no	yes	yes	
C14EO2S	SU	N		yes	1.8	no	1.0E-04	no	yes	yes	
C14EO3S	SU	N		yes	1.7	no	1.0E-04	no	yes	yes	
C14EO4S	SU	N		yes	1.7	no	1.0E-04	no	yes	yes	

c. Included studies

Table 4 briefly describes the scientific papers included for the final database used for the meta-analysis.

Table 4 – Scientific papers used for the meta-analysis of the removal efficiency of surfactants, fragrances, and pharmaceuticals in activated sludge wastewater treatment plants.

Reference	Chemical Type	Country	Sampling Period	Method
Artola-Garciano, et al. [87]	Fragrance	Netherlands	From March 5 to April 24, 2001	Grab sample and total concentration measured. Mean given. Variance given.
Berset, et al. [88]	Fragrance	Switzerland	April, 2001	24h composite sample and total concentration measured. Mean given. Variance imputed.
Bester [89]	Fragrance	Germany	April 2002	24h composite sample and total concentration measured. Mean given. Variance given.
Carballa, et al. [90]	Fragrance	Spain	October 2001- April 2002	24h composite sample and total concentration measured. Mean from raw data. Variance from raw data.
Chen, et al. [91]	Fragrance	China	15-22 November 2004	24h composite sample and total concentration measured. Mean given. Variance given.
Clara, et al. [35]	Fragrance	Austria	Not given	24h composite sample and dissolved concentration measured. Mean given. Variance imputed.
Clara, et al. [36]	Fragrance	Austria	Not given	24h composite sample and total concentration measured. Mean given. Variance imputed.
Dsikowitzky, et al. [92]	Fragrance	Germany	22 August 1999	Grab sample and dissolved concentration measured. Mean given. Variance imputed.
Godayol, et al. [93]	Fragrance	Spain	Jan - March 2013	Grab sample and dissolved concentration measured. Mean given. Variance given.
He, et al. [94]	Fragrance	China	July 2011	Mixed from samples, also at three different positions and dissolved concentration measured. Mean given. Variance given.
Horii, et al. [95]	Fragrance	USA	9 February 2005	Grab sample and dissolved concentration measured. Mean from raw data. Variance from raw data.

Kanda, et al. [18]	Fragrance	United Kingdom	December 2001 (17-18 or 10-12)	24h composite sample and dissolved concentration measured. Mean given. Variance given.
Kupper, et al. [96]	Fragrance	Switzerland	Spring 2002	24h composite sample and total concentration measured. Mean given. Variance given.
Reiner, et al. [97]	Fragrance	USA	October 16-20, 2005	24h composite sample and total concentration measured. Mean given. Variance given.
Ren, et al. [23]	Fragrance	China	Nov.2010-Jan.2011	24h composite sample and dissolved concentration measured. Mean from graph. Variance imputed.
Rosal, et al. [98]	Fragrance, Pharmaceutical	Spain	Before 2009	Type of sample not known and dissolved concentration measured. Mean given. Variance imputed.
Salgado, et al. [99]	Fragrance	Portugal	Not given	24h composite sample and dissolved concentration measured. Mean from raw data. Variance from raw data.
Simonich, et al. [100]	Pharmaceutical	USA	September 1997	24h composite sample and total concentration measured. Mean given. Variance given.
Smyth, et al. [101]	Pharmaceutical	Canada	warm: August 2003 - April 2005	24h composite sample and dissolved concentration measured. Mean given. Variance given.
Ternes, et al. [102]	Pharmaceutical	Germany	February, May, September, and October 2026	24h composite sample and dissolved concentration measured. Mean given. Variance given.
Vallecillos, et al. [34]	Pharmaceutical	Spain	3 months period	Grab sample and dissolved concentration measured. Mean from range. Variance imputed.
Yang and Metcalfe [103]	Pharmaceutical	Canada	July 2003	24h composite sample and dissolved concentration measured. Mean from raw data. Variance from raw data.
Zeng, et al. [104]	Pharmaceutical	China	23 October 2004	24h composite sample and total concentration measured. Mean given. Variance given.
Zhou, et al. [105]	Pharmaceutical	China	October to December 2007	Grab sample and dissolved concentration measured. Mean from range. Variance imputed.

Alder, et al. [106]	Pharmaceutical	Switzerland	August 14 - 21 2006	24h composite sample and dissolved concentration measured. Mean given. Variance given.
Andersen, et al. [107]	Pharmaceutical	Germany	November 2001	24h composite sample and dissolved concentration measured. Mean given. Variance imputed.
Aymerich, et al. [75]	Pharmaceutical	Spain	8-11 October 2012	Grab samples and dissolved concentration measured. Mean given. Variance given.
Bahlmann, et al. [58]	Pharmaceutical	Germany	Spring-Summer 2010	24h composite sample and total concentration measured. Mean given. Variance imputed.
Baronti, et al. [108]	Pharmaceutical	Italy	October 1999	24h composite sample and dissolved concentration measured. Mean from raw data. Variance from raw data.
Batt, et al. [109]	Pharmaceutical	USA	March 2006	24h composite sample and total concentration measured. Mean given. Variance given.
Batt, et al. [110]	Pharmaceutical	USA	April 2005	Grab samples and total concentration measured. Mean given. Variance given.
Belhaj, et al. [13]	Pharmaceutical	Tunisia	April 2010	Grab sample and dissolved concentration measured. Mean from graph. Variance imputed.
Bendz, et al. [55]	Pharmaceutical	Sweden	October 2002	24h composite sample and dissolved concentration measured. Mean given. Variance imputed.
Bijlsma, et al. [111]	Pharmaceutical	Netherlands	February 2010	24h composite sample and dissolved concentration measured. Mean given. Variance imputed.
Birosova, et al. [112]	Pharmaceutical	Slovakia	February 2013	24h composite sample and dissolved concentration measured. Mean given. Variance given.
Blair, et al. [113]	Pharmaceutical	USA	6 dates over Spring 2009-Fall 2010	24h composite sample and dissolved concentration measured. Mean from median. Variance imputed.
Bollmann, et al. [114]	Pharmaceutical	Germany	Not given	24h composite sample and total concentration measured. Mean given. Variance imputed.
Braga, et al. [115]	Pharmaceutical	Australia	Not given	Grab samples and dissolved concentration measured. Mean given. Variance given.
Camacho-Muñoz, et al. [116]	Pharmaceutical	Spain	May, September 2008, January 2009	24h composite sample and dissolved concentration measured. Mean from range. Variance imputed.

Celiz, et al. [117]	Pharmaceutical	Spain	July 2007	24h composite sample and dissolved concentration measured. Mean given. Variance given.
Chang, et al. [118]	Pharmaceutical	China	Week June-July 2006	24h composite sample and dissolved concentration measured. Mean from raw data. Variance from raw data.
Choi, et al. [48]	Pharmaceutical	South Korea	April 2005	Grab sample and dissolved concentration measured. Mean from raw data. Variance from raw data.
Collado, et al. [119]	Pharmaceutical	Spain	16-20 May 2011; 16-20 January 2012, 6-10 August 2012	48h composite sample and dissolved concentration measured. Mean given. Variance given.
Drewes, et al. [120]	Pharmaceutical	USA	Not given	4h composite sample and dissolved concentration measured. Mean given. Variance imputed.
Duan, et al. [15]	Pharmaceutical	China	22 December 2010; 4 and 8 January 2011	8h composite sample and total concentration measured. Mean given. Variance given.
Estrada-Arriaga, et al. [121]	Pharmaceutical	Mexico	July 2013	24h composite sample and dissolved concentration measured. Mean from raw data. Variance from raw data.
Evans, et al. [122]	Pharmaceutical	United Kingdom	Not given	Grab samples and dissolved concentration measured. Mean given. Variance given.
Froehner, et al. [123]	Pharmaceutical	Brasil	May to December 2009	Sample type not mentioned and dissolved concentration measured. Mean given. Variance given.
Gagnon and Lajeunesse [124]	Pharmaceutical	Canada	Spring to fall	24h composite sample and dissolved concentration measured. Mean given. Variance given.
Gao, et al. [125]	Pharmaceutical	USA	May to December 2010	Three 6h and three 24h composite samples and dissolved concentration measured. Mean given. Variance given.
Gardner, et al. [126]	Pharmaceutical	United Kingdom	Year 2010-2011	Grab samples and total concentration measured. Mean from raw data. Variance from raw data.
Ghosh, et al. [11]	Pharmaceutical	Japan	Not given	Grab samples and dissolved concentration measured. Mean given. Variance imputed.

Golovko, et al. [50]	Pharmaceutical	Czech Republic	March 2011-February 2012	24h composite sample and dissolved concentration measured. Mean from median. Variance imputed.
Gomez, et al. [84]	Pharmaceutical	Spain	2007-2008	24h composite sample and total concentration measured. Mean given. Variance imputed.
Gracia-Lor, et al. [127]	Pharmaceutical	Spain	April 2009 and October 2009	24h composite sample and total concentration measured. Mean from median. Variance imputed.
Guerra, et al. [128]	Pharmaceutical	Canada	11 March 2011	24h composite sample and dissolved concentration measured. Mean from raw data. Variance from raw data.
Gulkowska, et al. [52]	Pharmaceutical	Hong Kong	December 2006	Grab samples and dissolved concentration measured. Mean given. Variance given.
Gurke, et al. [129]	Pharmaceutical	Germany	January-february 2015	24h composite sample and dissolved concentration measured. Mean given. Variance given.
Gurke, et al. [130]	Pharmaceutical	Germany	11 May 2014	24h composite sample and dissolved concentration measured. Mean from raw data. Variance from raw data.
Hijosa-Valsero, et al. [131]	Pharmaceutical	Spain	July and August 2008	Grab samples and dissolved concentration measured. Mean given. Variance imputed.
Hollender, et al. [132]	Pharmaceutical	Switzerland	September 2007	24h composite sample and dissolved concentration measured. Mean from raw data. Variance from raw data.
Jelic, et al. [9]	Pharmaceutical	Spain	July 2007-March 2009	24h composite sample and dissolved concentration measured. Mean from median. Variance imputed.
Johnson, et al. [6]	Pharmaceutical	United Kingdom	June 2012	24h composite sample and dissolved concentration measured. Mean from raw data. Variance from raw data.
Jones, et al. [17]	Pharmaceutical	United Kingdom	14th June 2004	Grab sample and dissolved concentration measured. Mean from raw data. Variance from raw data.
Joss, et al. [133]	Pharmaceutical	Switzerland	22-24 November 2002	24h composite sample and dissolved concentration measured. Mean given. Variance imputed.
Joss, et al. [134]	Pharmaceutical	Switzerland	20-22 November 2002	24h composite sample and dissolved concentration measured. Mean given. Variance given.

Kanda, et al. [18]	Pharmaceutical	United Kingdom	December 2001	Composite sample and dissolved concentration measured. Mean given. Variance given.
Karthikeyan and Meyer [135]	Pharmaceutical	USA	6 December 2001	24h composite sample and dissolved concentration measured. Mean given. Variance given.
Kasprzyk-Hordern, et al. [73]	Pharmaceutical	United Kingdom	April-August 2007	24h composite sample and dissolved concentration measured. Mean given. Variance imputed.
Kimura, et al. [136]	Pharmaceutical	Japan	August-October 2005	Grab samples and dissolved concentration measured. Mean given. Variance given.
Komesli, et al. [53]	Pharmaceutical	Turkey	Not given	24h composite sample and dissolved concentration measured. Mean given. Variance imputed.
Kruglova, et al. [20]	Pharmaceutical	Finland	December 2011-February 2012	24h composite sample and total concentration measured. Mean from graph. Variance imputed.
Kümmerer, et al. [41]	Pharmaceutical	Germany	May 1995	1h composite sample and dissolved concentration measured. Mean from median. Variance from raw data.
Lajeunesse, et al. [137]	Pharmaceutical	Canada	September 2009	24h composite sample and dissolved concentration measured. Mean given. Variance given.
Larsson, et al. [74]	Pharmaceutical	Sweden	15, 22, 29 April 2013	Grab samples and total concentration measured. Mean from range. Variance imputed.
Leclercq, et al. [138]	Pharmaceutical	France	Not given	24h composite sample and dissolved concentration measured. Mean given. Variance imputed.
Leung, et al. [139]	Pharmaceutical	Hong Kong	June and August 2011	24h composite sample and dissolved concentration measured. Mean given. Variance given.
Li and Zhang [5]	Pharmaceutical	Hong Kong	March 2009	24h composite sample and dissolved concentration measured. Mean from raw data. Variance from raw data.
Lindberg, et al. [140]	Pharmaceutical	Sweden	April 2002	Weekly composite sample and dissolved concentration measured. Mean from raw data. Variance from raw data.
Lindqvist, et al. [21]	Pharmaceutical	Finland	September 2003	24h composite sample and dissolved concentration measured. Mean from graph. Variance imputed.

Loganathan, et al. [141]	Pharmaceutical	USA	9 February 2007	Grab samples and dissolved concentration measured. Mean from raw data. Variance from raw data.
Mackulak, et al. [142]	Pharmaceutical	Slovakia	23 October 2013	Grab samples and dissolved concentration measured. Mean given. Variance given.
Manickum and John [45]	Pharmaceutical	South Africa	March 2010 to June 2012	Grab samples and total concentration measured. Mean given. Variance given.
Martin, et al. [143]	Pharmaceutical	Spain	January 2008-January 2009	24h composite sample and dissolved concentration measured. Mean given. Variance imputed.
Matongo, et al. [144]	Pharmaceutical	South Africa	September 2013	Grab samples and dissolved concentration measured. Mean given. Variance given.
Metcalfe, et al. [145]	Pharmaceutical	Canada	December 1998	24h composite sample and dissolved concentration measured. Mean given. Variance imputed.
Morasch, et al. [146]	Pharmaceutical	Switzerland	20 February - 11 March 2009	24h composite sample and dissolved concentration measured. Mean given. Variance given.
Nakada, et al. [147]	Pharmaceutical	Japan	July 2002	24h composite sample and dissolved concentration measured. Mean from raw data. Variance from raw data.
Nie, et al. [148]	Pharmaceutical	China	Summer 2009	Grab samples and dissolved concentration measured. Mean given. Variance given.
Oliveira, et al. [149]	Pharmaceutical	USA	End of October-early November 2013	24h composite sample and dissolved concentration measured. Mean given. Variance given.
Papageorgiou, et al. [150]	Pharmaceutical	Greece	Spring 2013-2014	24h composite sample and dissolved concentration measured. Mean given. Variance imputed.
Patrolecco, et al. [151]	Pharmaceutical	Italy	May 2011	24h composite sample and dissolved concentration measured. Mean given. Variance given.
Pereira, et al. [152]	Pharmaceutical	Portugal	Spring 2013 (14 May-4 June)	24h composite sample and dissolved concentration measured. Mean from raw data. Variance from raw data.
Qi, et al. [22]	Pharmaceutical	China	March 2011	24h composite sample and dissolved concentration measured. Mean from graph. Variance imputed.

Radjenovic, et al. [153]	Pharmaceutical	Spain	March and April 2007	24h composite sample and dissolved concentration measured. Mean given. Variance imputed.
Repice, et al. [154]	Surfactant	Italy	25th July to 9th August 2010	24h composite sample and dissolved concentration measured. Mean from raw data. Variance from raw data.
Rodríguez, et al. [155]	Fragrance	Spain	October 2001	24h composite sample and dissolved concentration measured. Mean from raw data. Variance from raw data.
Rubirola, et al. [156]	Fragrance	Spain	Day 1 April 2013	Grab sample and dissolved concentration measured. Mean from raw data. Variance from raw data.
Ryu, et al. [157]	Fragrance	South Korea	May 2013	Grab samples and dissolved concentration measured. Mean given. Variance imputed.
Samaras, et al. [158]	Pharmaceutical	Greece	June, July, September 2009	24h composite sample and total concentration measured. Mean given. Variance given.
Santos, et al. [159]	Pharmaceutical	Spain	July to September 2004	24h composite sample and dissolved concentration measured. Mean given. Variance given.
Santos, et al. [160]	Pharmaceutical	Spain	June 2004 to June 2005	24h composite sample and dissolved concentration measured. Mean given. Variance given.
Sari, et al. [161]	Pharmaceutical	Turkey	Summer 2012	24h composite sample and dissolved concentration measured. Mean given. Variance given.
Schlusener, et al. [162]	Pharmaceutical	Germany	May 2012	24h composite sample and dissolved concentration measured. Mean given. Variance given.
Senta, et al. [163]	Pharmaceutical	Croatia	March to September 2011	24h composite sample and total concentration measured. Mean given. Variance given.
Servos, et al. [24]	Pharmaceutical	Canada	9 December 1998	24h composite sample and dissolved concentration measured. Mean from graph. Variance imputed.
Shao and Ma [164]	Pharmaceutical	China	Year 2006-2007	Sample type not given and total concentration measured. Mean given. Variance given.
Stasinakis, et al. [165]	Pharmaceutical	Greece	December 2010-April 2011	24h composite sample and total concentration measured. Mean given. Variance imputed.

Stumpf, et al. [25]	Pharmaceutical	Brasil	June 1997	24h composite sample and dissolved concentration measured. Mean from graph. Variance imputed.
Subedi and Kannan [166]	Pharmaceutical	USA	July 2013	24h composite sample and dissolved concentration measured. Mean given. Variance imputed.
Tauxe-Wuersch, et al. [26]	Pharmaceutical	Switzerland	April 2002	24h composite sample and total concentration measured. Mean from graph. Variance imputed.
Thomas and Foster [167]	Pharmaceutical	USA	January 2004	24h composite sample and dissolved concentration measured. Mean given. Variance given.
Vergeynst, et al. [168]	Fragrance	Belgium	March 2013	Grab samples and dissolved concentration measured. Mean given. Variance given.
Vieno, et al. [169]	Fragrance	Finland	September 2003	Grab sample and dissolved concentration measured. Mean from raw data. Variance from raw data.
Wang, et al. [27]	Pharmaceutical	China	January 2013	24h composite sample and dissolved concentration measured. Mean from graph. Variance imputed.
Watkinson, et al. [170]	Pharmaceutical	Australia	Early 2006	Grab samples and total concentration measured. Mean from median. Variance imputed.
Wick, et al. [171]	Pharmaceutical	Germany	March, May, July 2007	24h composite sample and dissolved concentration measured. Mean from median. Variance imputed.
Xu, et al. [172]	Pharmaceutical	Hong Kong	May 2006	24h composite sample and dissolved concentration measured. Mean given. Variance given.
Yan, et al. [173]	Pharmaceutical	China	November, December 2012, January 2013	Grab samples and total concentration measured. Mean given. Variance given.
Yasojima, et al. [28]	Pharmaceutical	Japan	July to October 2004	24h composite sample and dissolved concentration measured. Mean given. Variance imputed.
Yu and Chu [174]	Pharmaceutical	USA	Not given	Grab samples and total concentration measured. Mean given. Variance imputed.
Yuan, et al. [175]	Pharmaceutical	China	November 2013	24h composite sample and dissolved concentration measured. Mean given. Variance given.
Zhou, et al. [29]	Pharmaceutical	China	June 2008 to May 2009	Grab samples and dissolved concentration measured. Mean from graph. Variance imputed.

Zorita, et al. [176]	Pharmaceutical	Sweden	June 2007; April 2008	24h composite sample and dissolved concentration measured. tbd. Variance given.
Camacho-Muñoz, et al. [177]	Pharmaceutical	Spain	July 2011 - June 2012	24h composite sample and total concentration measured. Mean given. Variance given.
Feijtel, et al. [80]	Surfactants	Netherlands	July 1, 1993	24h composite sample and total concentration measured. Mean from raw data. Variance from raw data.
Gomez, et al. [10]	Pharmaceutical	Spain	2010-2011	24h composite sample and dissolved concentration measured. Mean given. Variance imputed.
Gonzalez, et al. [16]	Surfactants	Spain	Not given	24h composite sample and dissolved concentration measured. Mean from median. Variance imputed.
González, et al. [8]	Surfactants	Spain	March 2007	24h composite sample and dissolved concentration measured. Mean from median. Variance imputed.
Gori, et al. [85]	Surfactants	Spain	Not given	24h composite sample and dissolved concentration measured. Mean given. Variance given.
Li, et al. [81]	Pharmaceutical	Germany	May - June 1999	Flow proportional grab samples and total concentration measured. Mean from range. Variance imputed.
Matthijs, et al. [178]	Surfactants	Netherlands	Not given	24h composite sample and total concentration measured. Mean given. Variance imputed.
McAvoy, et al. [179]	Surfactants	USA	Aug. 19-21 1992	24h composite sample and total concentration measured. Mean given. Variance imputed.

S4. Moderator selection

The data was structured into study, WWTP, and analysed chemical. A study could analyse different WWTPs as well as different chemicals. While a WWTP is the focus of a single study, a chemical could be analysed in various studies.

The moderators were selected following the procedure described in [180] from the set shown in Table 5. Firstly, moderators for which more than 65% of the studies did not report any information (data missing) were not considered to avoid a too large loss of data points.

Table 5 – Moderators available prior any screening from the raw data base. Reported as well is the number and percentage of available data points. RE stands for removal efficiency.

Moderator	Data available		Type
	[%]	[#]	
Technological			
Presence of primary settler	100.0	1539	Categorical: yes or no
Presence of micro screens	100.0	1539	Categorical: yes or no
Type of secondary treatment	100.0	1539	Categorical: sequencing batch reactor (SBR), completely stirred tank reactor (CSRT), plug-flow reactor (PFR), or oxidation ditch (OD)
Type of biological nutrient removal (BNR)	100.0	1539	Categorical: organic matter removal (OMR), nitrogen removal (NR), biological nutrient removal (BNR)
BNR implementation	100.0	1539	Categorical: yes or no
Presence of final settler	100.0	1539	Categorical: yes or no
Share of domestic influent [-]	69.5	1069	Continuous
Share of industrial influent [-]	69.5	1069	Continuous
Design capacity [m^3/d]	20.5	315	Continuous
Population served [PE]	77.3	1189	Continuous
Flow rate [m^3/d]	86.2	1326	Continuous
Sludge retention time (SRT) [d]	50.5	777	Continuous
Biological hydraulic retention time (HRT) [h]	31.3	482	Continuous

Total hydraulic retention time (HRT) [h]	45.2	696	Continuous
Influent pH [-]	31.1	478	Continuous
Secondary effluent pH [-]	8.5	131	Continuous
Effluent pH [-]	16.0	246	Continuous
Influent temperature [°C]	19.1	294	Continuous
Effluent temperature [°C]	8.9	137	Continuous
Volume of aerobic reactor [m^3]	13.6	209	Continuous
Volume of primary clarifier [m^3]	6.9	106	Continuous
Volume of secondary clarifier [m^3]	3.5	54	Continuous
RE of biological oxygen demand (BOD) [-]	35.3	543	Continuous
RE of chemical oxygen demand (COD) [-]	30.1	463	Continuous
RE of phosphorus [-]	26.3	404	Continuous
RE of nitrogen [-]	23.8	367	Continuous
RE of ammonium [-]	12.3	189	Continuous
RE of total suspended solids (TSS) [-]	31.6	486	Continuous
Physico-Chemical			
Chemical class	98.2	1511	Categorical: neutral, acid, base
Log K_{OW}	97.3	1498	Continuous
pKa [-]	69.3	1067	Continuous
Log K_{OC}	100.0	1539	Continuous
Henry's law constant [Pa m^3/mol]	99.9	1538	Continuous
Biodegradation rate [s^{-1}]	60.2	927	Continuous
Readily Biodegradable	100.0	1539	Categorical: yes or no
Biodegradation class	100.0	1539	Categorical

a. Outliers

Henry law's constant, vapour pressure, water solubility, flow rate, total HRT, population served, and SRT were log-transformed to reduce the influence of the few higher values.

b. Collinearity

Collinear moderators should not be kept together in a single model. We therefore chose the share of domestic influent over the share of industrial influent. The population served, which is a proxy for the design capacity of the plant, was dropped in favour of the flow rate as the latter had more data points and both were correlated. The SRT was preferred over the HRT on the one hand because it does not only reflect the retention time of particles in the WWTP, as shown by its slight correlation to HRT (Coefficient = 52.6%), but also gives indications on the microbial community present in the plant. On the other hand, the HRT was available for fewer datapoints compared to the SRT (507 vs 542). The categorical moderators describing the presence of a primary settler, micro screens, and a final settler were not considered further as they were not well balanced, as is exemplarily shown in Figure 3 for the relationship between the presence of a primary settler and the type of secondary treatment . It appears clearly that the majority of the designs implement a final settler.

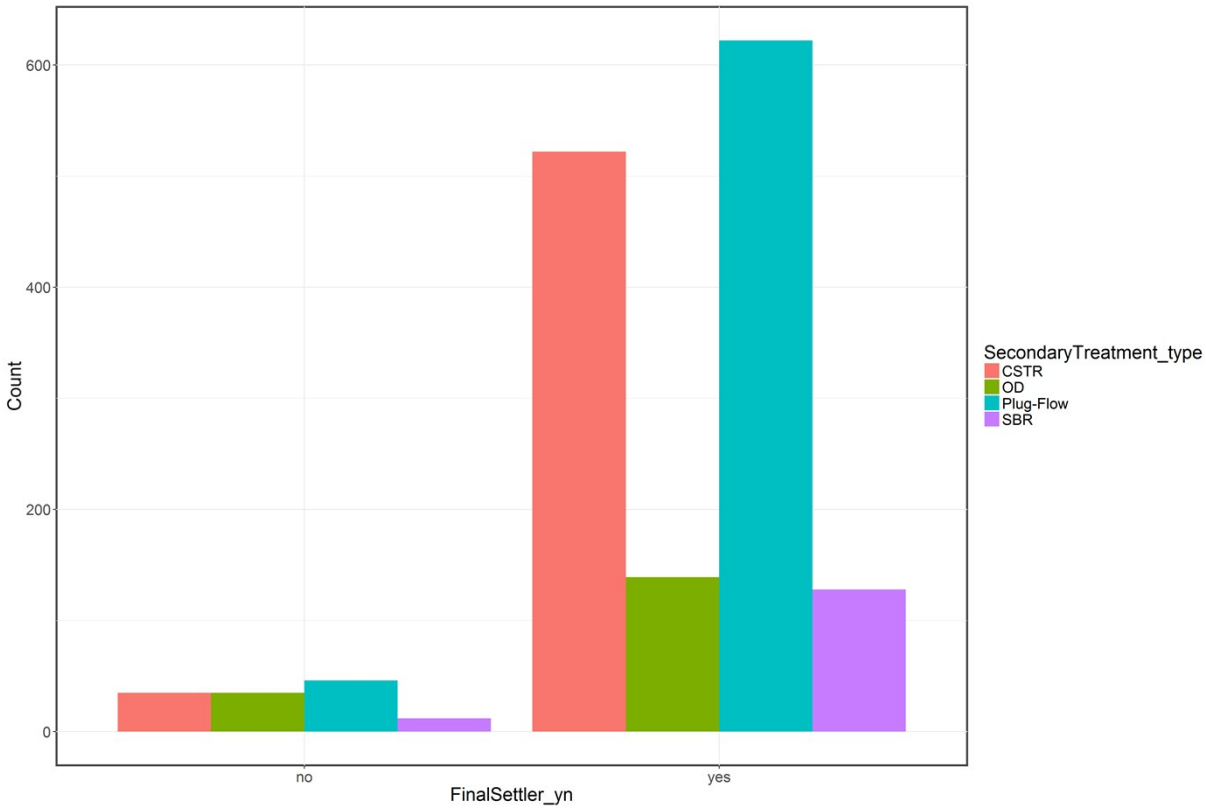

Figure 3 – Barplot describing the relationship between the final settler and the type of type of secondary treatment.

The log-transformed Henry Constant was preferred to the log K_{OW} as we expect it to describe other removal mechanisms. The log K_{OC} was preferred to the pKa. The biodegradation rate was also dropped as it had missing data points and was well represented by both categorical moderators describing

biodegradability. Further, since the chemical class was used to compute the log K_{OC}, it was also not retained as potential moderator (Figure 4).

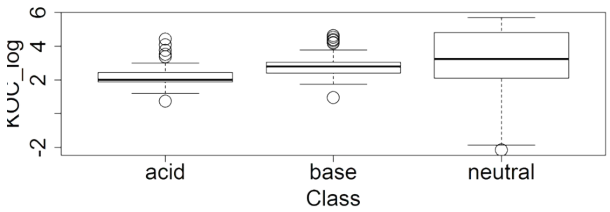

Figure 4 – Boxplot describing the relationship between the chemical class and the log K_{OC}.

The following relationships were also identified but a final decision on which moderator to use could not be made at this point.

- Type of BNR or BNR implementation
- Type of BNR or secondary treatment type
- BNR implementation or secondary treatment type
- Flow rate or secondary treatment type
- SRT or secondary treatment type
- Readily Biodegradable or Biodegradation category

c. Relation to effect size

The final set of moderators was derived using univariate models relating the 10 single moderators left to the effect size. The results of the Omnibus moderator test (Table 6) was used for this sake. The readily biodegradability categorisation was preferred to the biodegradability category because it was significant according to the Omnibus test. The BNR implementation was retained over the BNR type. The SRT was preferred over the secondary treatment type, because it was significantly influencing the effect size and it allowed to include the flow rate and the BNR implementation in the final moderator set.

Table 6 – Results of the Omnibus moderator test conducted for each univariate model and ranked according to the Q_M value

Moderator	Q_M	p-value
Readily biodegradable	24.57	7.16E-07
Log SRT	4.46	0.03
Type of secondary treatment	4.15	0.25

Log K_{OC}	3.64	0.06
Log flow rate	3.16	0.08
Type of BNR	1.61	0.45
BNR implementation	1.15	0.28
Log Henry constant	1.10	0.29
Biodegradation category	0.42	0.52
Share domestic influent	0.16	0.69

Further, Figure 5 visualises the relationships between the removal efficiency and (1) K_{OC}, (2) flow rate, (3) Henry law constant, and (4) share of domestic influent. In Figure 6 to Figure 8 the mean weighted removal efficiency is shown in relation to the biodegradability category, the type of biological nutrient removal, and the type of secondary treatment.

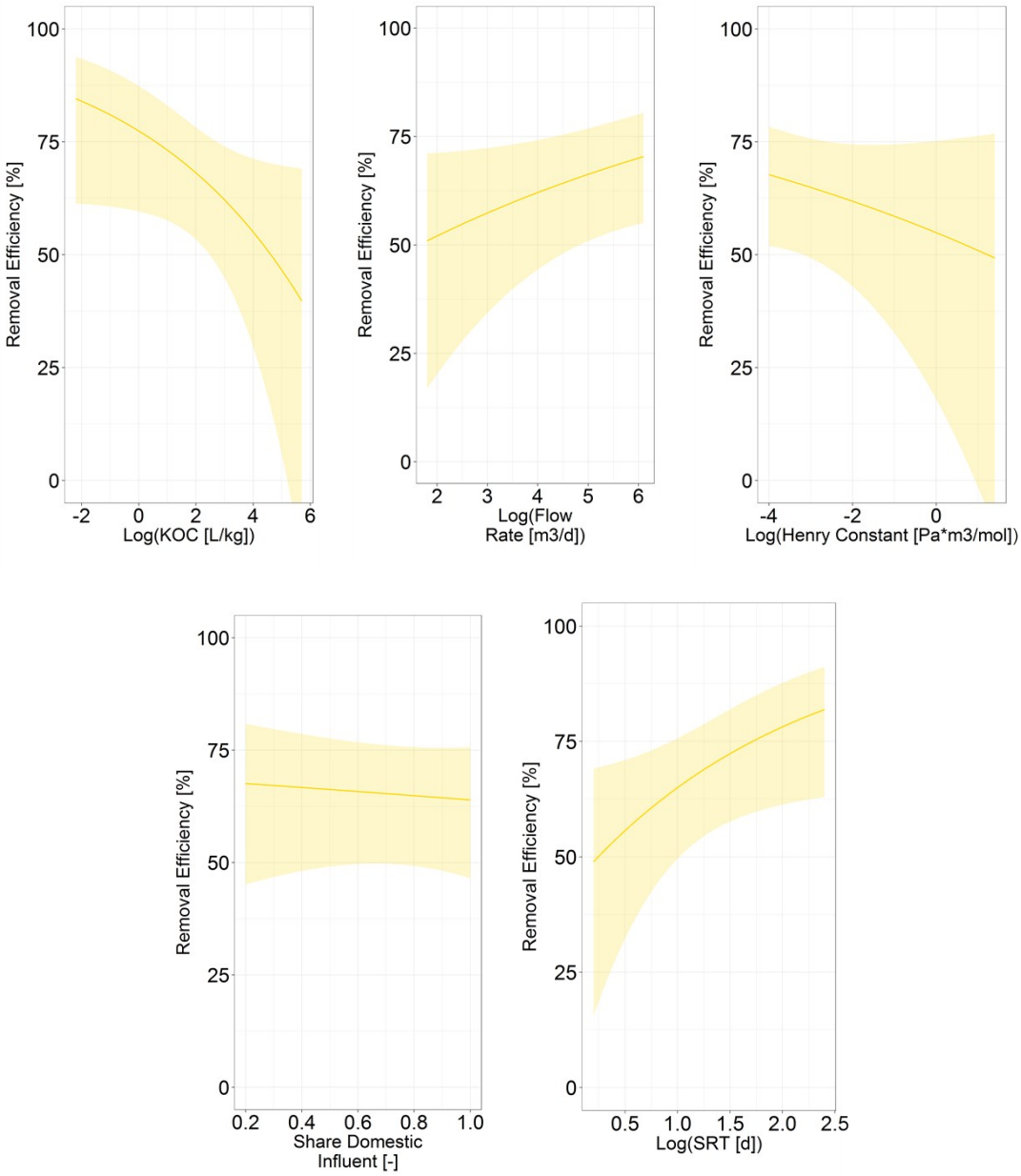

Figure 5 – Univariate models showing the relationship between the removal efficiency and (1) the log KOC, (2) the log of the flow rate, (3) the log of the Henry constant, (4) the share of domestic influent, and (5) the log of the sludge retention time. The shaded areas represent the 95% confidence interval.

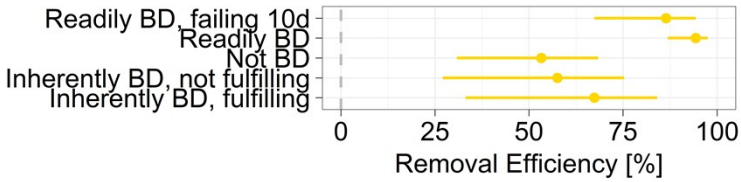

Figure 6 – Mean weighted removal efficiency with 95th confidence interval for the different biodegradability classes.

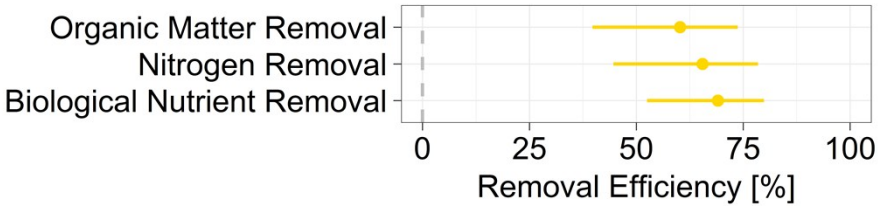

Figure 7 – Mean weighted removal efficiency with 95 th confidence interval for the biological nutrient removal classes.

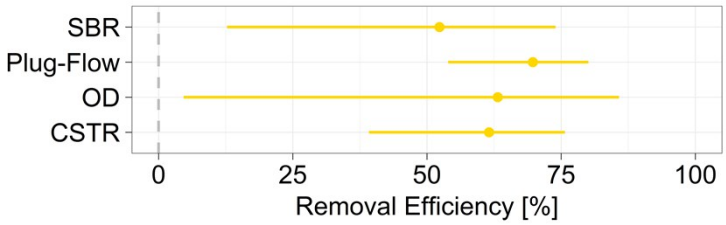

Figure 8 – Mean weighted removal efficiency with 95 th confidence interval for the different designs of secondary treatment types.

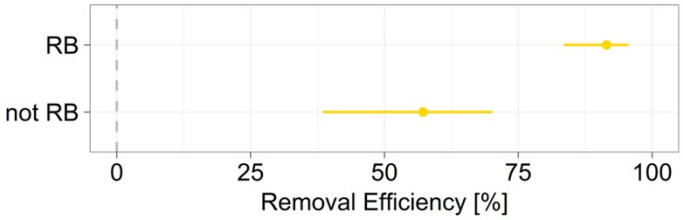

Figure 9 – Mean weighted removal efficiency with 95% confidence interval for readily biodegradable (RB) and not readily biodegradable (not RB) chemicals, when a univariate model was fitted to the data.

S5. Choice of random effects

The optimal random effect structure included the chemical, and the plant codes nested within each study (Table 7).

Table 7 – Random effect structures ranked according to their Bayesian Information Criteria (BIC).

RandomEffects	BIC
~1|Chemical_Name,~1|Reference/Plant.code	13 933
~1|Chemical_Name,~1|Country,~1|Reference/Plant.code	13 939
~1|Chemical_Name,~1|Reference,~1|Reference/Plant.code	13 939
~1|Chemical_Name,~1|Country,~1|Reference,~1|Reference/Plant.code	13 945

~1|Chemical_Name,~1|Reference	14 521
~1|Chemical_Name,~1|Country,~1|Reference	14 527
~1|Chemical_Name,~1|Country	19 820
~1|Chemical_Name	27 374
~1|Reference/Plant.code	65 347
~1|Reference,~1|Reference/Plant.code	65 353
~1|Country,~1|Reference/Plant.code	65 353
~1|Country,~1|Reference,~1|Reference/Plant.code	65 360
~1|Reference	66 580
~1|Country,~1|Reference	66 586
~1|Country	85 267

Table 8 shows the contribution of each random effect to the total variance accounted for by the random effects.

Table 8 – Contribution of each random effect to the total variance for the reduced dataset (N=542)

Contribution to variance [%]	
Sampling variance	0.2
Chemical name	52.4
Reference	40.9
Plant code (nested in Reference)	6.53

S6. Final model

a. Moderator selection

Table 9 lists the combinations of moderators tested together with the BIC value and the assigned weight for which the Akaike weight was above 0.1%.

Table 9 – Combination of moderators tested to choose the final model. They are ranked according to their Bayesian Information Criterion (BIC) and the corresponding weight used for the model averaging is also listed.

Model	BIC	Weights
EffectSize ~ 1 + ReadilyBiodegradable + log_SRT_d + KOC_log + ReadilyBiodegradable:log_SRT_d + ReadilyBiodegradable:KOC_log	14641.5	0.55
EffectSize ~ 1 + ReadilyBiodegradable + log_SRT_d + ReadilyBiodegradable:log_SRT_d	14643.9	0.17
EffectSize ~ 1 + ReadilyBiodegradable + log_FlowRate_m3d + log_SRT_d + KOC_log + ReadilyBiodegradable:log_SRT_d + ReadilyBiodegradable:KOC_log	14645.2	0.09
EffectSize ~ 1 + ReadilyBiodegradable + log_SRT_d + KOC_log + ReadilyBiodegradable:log_SRT_d	14646.5	0.04
EffectSize ~ 1 + ReadilyBiodegradable + log_FlowRate_m3d + log_SRT_d + ReadilyBiodegradable:log_SRT_d	14647.5	0.03
EffectSize ~ 1 + ReadilyBiodegradable + log_SRT_d + log_HC + KOC_log + ReadilyBiodegradable:log_SRT_d + ReadilyBiodegradable:KOC_log	14647.8	0.02
EffectSize ~ 1 + ReadilyBiodegradable + NatureInfluent_ShareDomestic + log_SRT_d + KOC_log + ReadilyBiodegradable:log_SRT_d + ReadilyBiodegradable:KOC_log	14647.8	0.02
EffectSize ~ 1 + ReadilyBiodegradable + KOC_log + ReadilyBiodegradable:KOC_log	14649.1	0.01
EffectSize ~ 1 + ReadilyBiodegradable + log_SRT_d + log_HC + ReadilyBiodegradable:log_SRT_d	14649.6	0.01
EffectSize ~ 1 + ReadilyBiodegradable + NatureInfluent_ShareDomestic + log_SRT_d + ReadilyBiodegradable:log_SRT_d	14650.2	0.01
EffectSize ~ 1 + ReadilyBiodegradable + log_FlowRate_m3d + log_SRT_d + KOC_log + ReadilyBiodegradable:log_SRT_d	14650.2	0.01
EffectSize ~ 1 + ReadilyBiodegradable + log_SRT_d + KOC_log + ReadilyBiodegradable:KOC_log	14650.9	0.01
EffectSize ~ 1 + ReadilyBiodegradable + log_FlowRate_m3d + log_SRT_d + log_HC + KOC_log + ReadilyBiodegradable:log_SRT_d + ReadilyBiodegradable:KOC_log	14651.5	0.00
EffectSize ~ 1 + ReadilyBiodegradable + NatureInfluent_ShareDomestic + log_FlowRate_m3d + log_SRT_d + KOC_log + ReadilyBiodegradable:log_SRT_d + ReadilyBiodegradable:KOC_log	14651.5	0.00
EffectSize ~ 1 + ReadilyBiodegradable	14651.7	0.00
EffectSize ~ 1 + ReadilyBiodegradable + log_FlowRate_m3d + KOC_log + ReadilyBiodegradable:KOC_log	14652.5	0.00

EffectSize ~ 1 + ReadilyBiodegradable + log_SRT_d + log_HC + KOC_log + ReadilyBiodegradable:log_SRT_d	14652.8	0.00
EffectSize ~ 1 + ReadilyBiodegradable + NatureInfluent_ShareDomestic + log_SRT_d + KOC_log + ReadilyBiodegradable:log_SRT_d	14652.8	0.00
EffectSize ~ 1 + ReadilyBiodegradable + log_FlowRate_m3d + log_SRT_d + log_HC + ReadilyBiodegradable:log_SRT_d	14653.3	0.00
EffectSize ~ 1 + ReadilyBiodegradable + log_SRT_d	14653.5	0.00
EffectSize ~ 1 + ReadilyBiodegradable + NatureInfluent_ShareDomestic + log_FlowRate_m3d + log_SRT_d + ReadilyBiodegradable:log_SRT_d	14653.8	0.00
EffectSize ~ 1 + BNR_Type + ReadilyBiodegradable + log_SRT_d + KOC_log + ReadilyBiodegradable:log_SRT_d + ReadilyBiodegradable:KOC_log	14653.9	0.00
EffectSize ~ 1 + ReadilyBiodegradable + log_FlowRate_m3d + log_SRT_d + KOC_log + ReadilyBiodegradable:KOC_log	14653.9	0.00
EffectSize ~ 1 + ReadilyBiodegradable + NatureInfluent_ShareDomestic + log_SRT_d + log_HC + KOC_log + ReadilyBiodegradable:log_SRT_d + ReadilyBiodegradable:KOC_log	14654.1	0.00

b. Omnibus test results

Table 10 shows the Omnibus test results for the final model.

Table 10 – Omnibus test results (Q_M) and p-value for the moderators retained in the final model.

Moderator	Q_M	p-value
Readily Biodegradability	21.79	3.05E-06
Log K_{OC}	15.65	7.63E-05
Interaction Readily Biodegradability and log K_{OC}	11.52	6.90E-04
Log SRT	3.62	5.71E-02
Interaction Readily Biodegradability and log SRT	1.43	2.32E-01

c. Testing assumptions

The residuals were plotted against the fitted values to test for the homogeneity in the residuals (Figure 10). The spread is rather homogeneous with a slight tendency towards negative values, and thus this assumption is not violated.

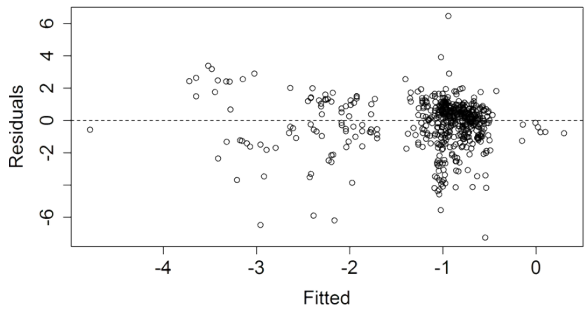

Figure 10 – Residuals of the final model plotted against the fitted values.

The moderators used in the final model were plotted against the residuals to make sure that the independence assumption was respected. Considering the lack of trend in Figure 11, this assumption is not violated.

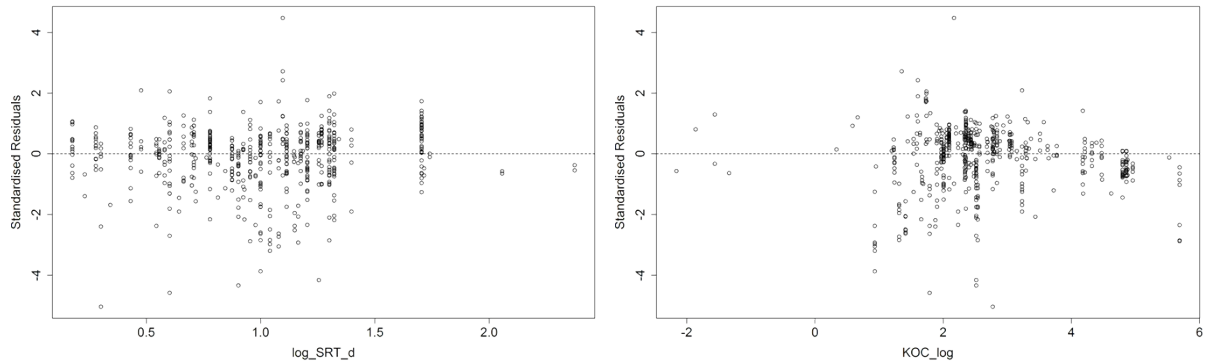

Figure 11 – Residuals plotted against the continuous moderators used in the final descriptive model.

Finally, the normality of the residuals was also assessed using histogram and QQ-plot (Figure 12). The QQ plot shows a slight deviation of low and high residuals from normality. Since the deviation was not too large and the histogram rather spoke in favour of a normal distribution of the residuals, we assumed that the normality assumption was not violated.

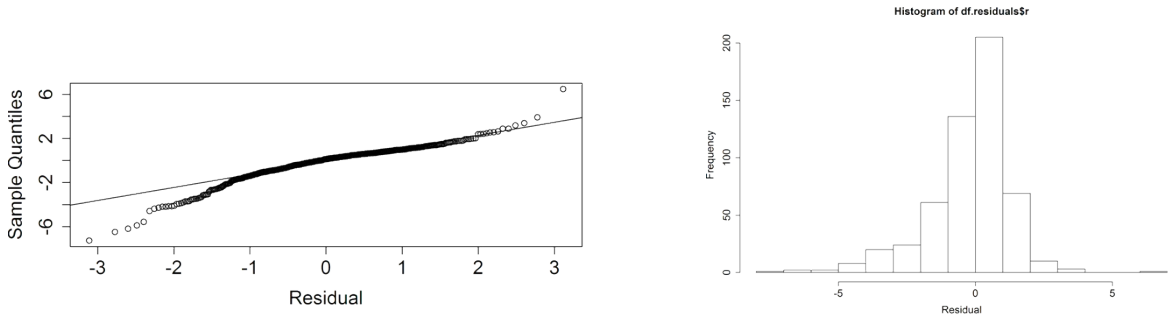

Figure 12 – Testing the normality of the residuals using QQ-plots (left) and histogram (right)

Similar results were obtained for the model fitted on the dataset with data points of good or moderate quality criteria only.

d. Publication bias

The Funnel plot and Egger test conducted on the available database show that our model is robust against potential publication bias (Figure 13).

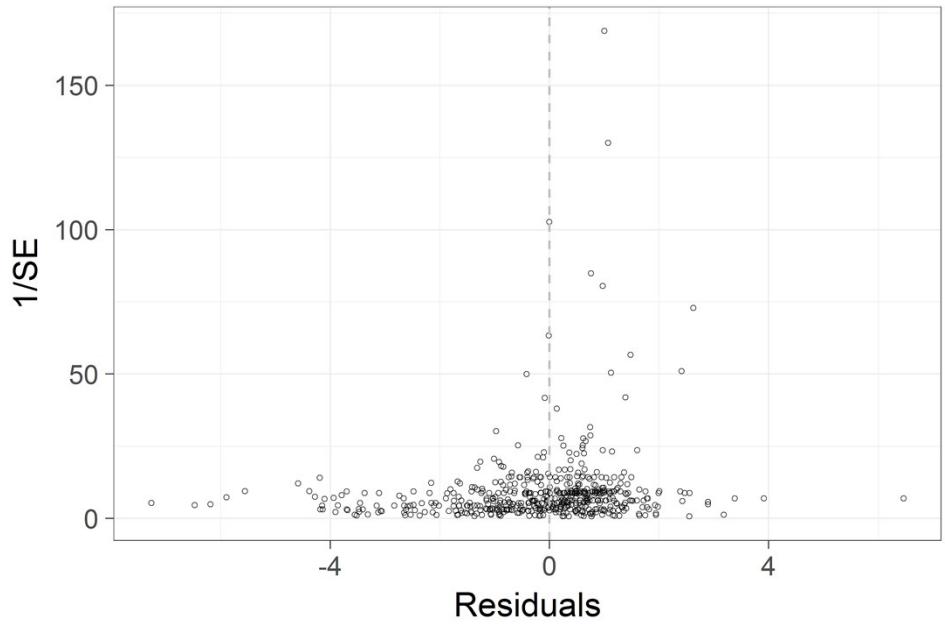

Figure 13 – Funnel plot of the studies included in the final model showing the relationship between the inverse of the standard error and the residuals. The Egger test gave an intercept of 0.14 (95% CI: -0.22- 0.50, P =0.43).

S7. Sensitivity to data quality

a. Influence of SRT and K_{OC}

Figure 14 and Figure 15 show the increase in RE with increased SRT and K_{OC} for readily and non-readily biodegradable compounds for the database excluding studies with poor quality criteria (N=193).

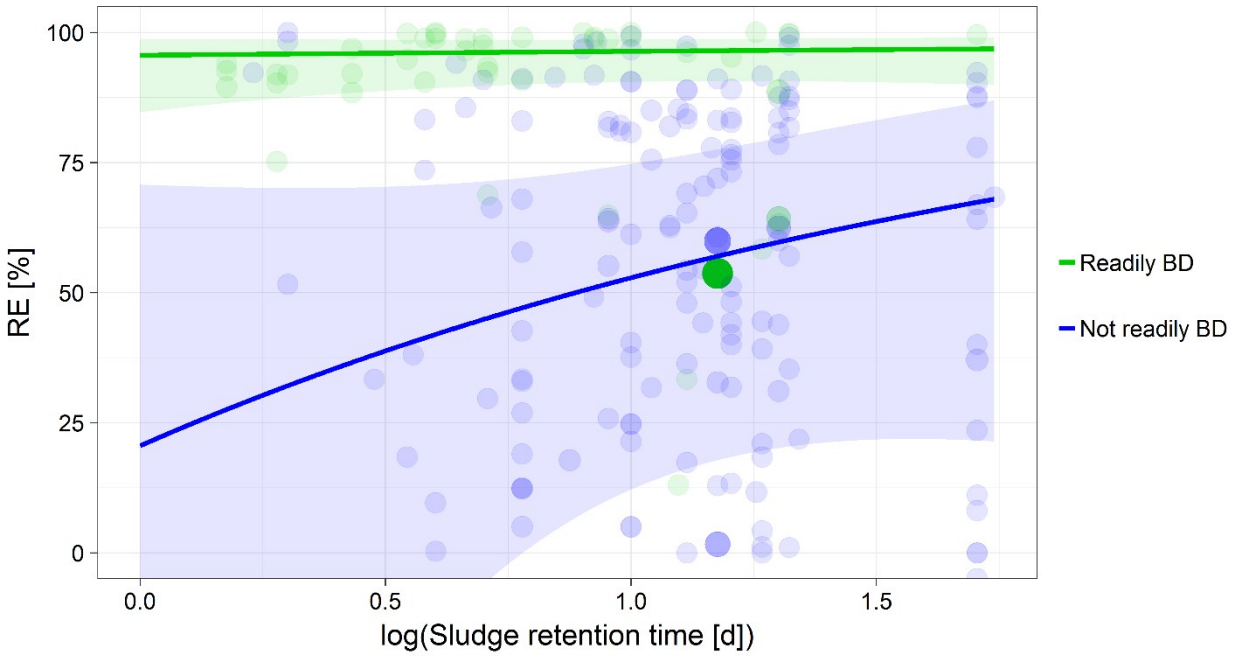

Figure 14 – Removal efficiency [%] as a function of the log of the sludge retention time [d] for the readily biodegradable (readily BD) and not readily biodegradable (not readily BD) chemicals. The shaded areas represent the 95th confidence interval. The dots represent the different effect sizes included in the analysis (N = 193). The size and colour intensity of the dots indicate their weight in the meta-analysis. Blue dots refer to not readily biodegradable compounds, while green dots are readily biodegradable compounds.

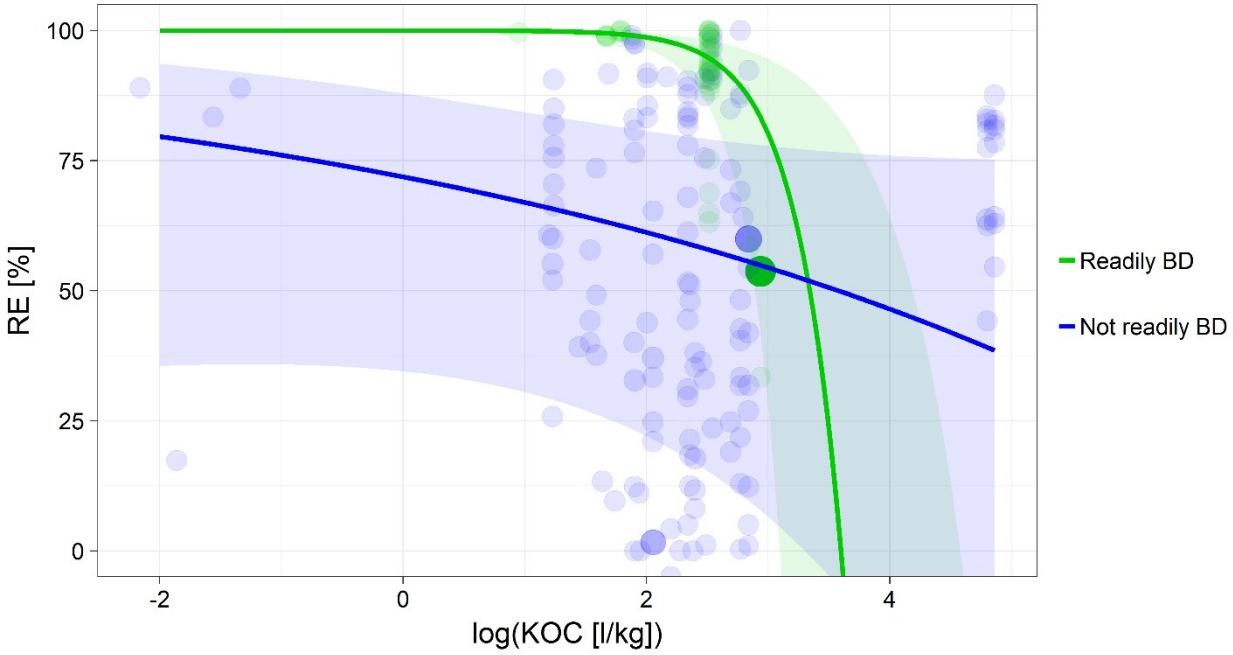

Figure 15 – Removal efficiency [%] as a function of the log K_{OC} for the readily biodegradable (readily BD) and not readily biodegradable (not readily BD) chemicals. The shaded areas represent the 95th confidence interval. The dots represent the

different effect sizes included in the analysis (N = 193). The size and colour intensity of the dots indicate their weight in the meta-analysis. Blue dots refer to not readily biodegradable compounds, while green dots are readily biodegradable compounds.

b. Omnibus test results

Table 11 depicts the Omnibus test results for the moderators retained in the model fitted to the reduced dataset.

Table 11– Omnibus test results (Q_M) and p-value for the moderators retained in the model fitted to the reduced dataset.

Moderator	Q_M	p-value
Log Flow Rate	65.21	6.75E-16
Readily Biodegradability	57.54	3.31E-14
Log KOC	42.22	8.17E-11
Interaction Readily Biodegradability and log K_{OC}	22.44	2.17E-06
Log SRT	5.02	2.50E-02
Interaction Readily Biodegradability and log SRT	2.08	1.49E-01

c. Sensitivity to publication bias

The model fitted to the dataset excluding poor quality studies, might be slightly subject to publication bias. (Figure 16)

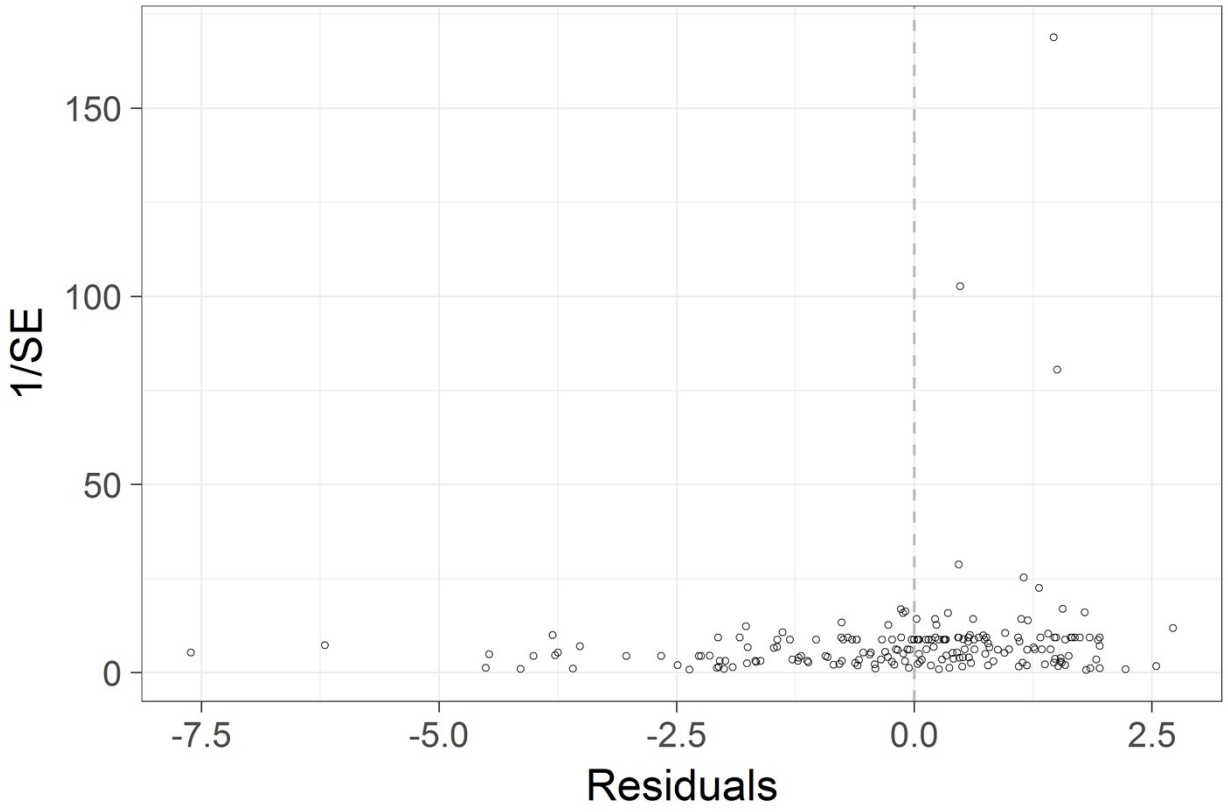

Figure 16 - Funnel plot of the studies included in the model fitted on the dataset excluding poor quality studies showing the relationship between the inverse of the standard error and the residuals. The Egger test gave an intercept of 0.13 (95% CI: -0.57-0.82, P =0.72).

S8. Imputation strategies

An additional assumption which might have induced bias in our analysis was to impute a standard deviation whenever missing. This was necessary for 47% of the reported effluent concentrations and for 38% of the reported influent concentrations. The larger percentage of imputed effluent concentration SD is due to the values measured below detection limits for which no SD could be reported even though they were for influent concentrations. Further, a sample size was imputed in approximately 19% of all cases (n=1539). However, the mean weighted removal efficiency was only slightly increased by this assumption (68.1% compared to 64.9% for the reduced database).

Using a different imputation strategy for missing SD had also little impact on the mean weighted removal (Figure 14). It appeared that imputations with Hot Deck led to a higher weighted removal efficiency (67.4%), which was however still clearly within the 95th CI of the default weighted RE. Similarly, the mean weighted removal efficiencies derived with Hot Deck Nearest Neighbour were all within the 95th CI of the default value.

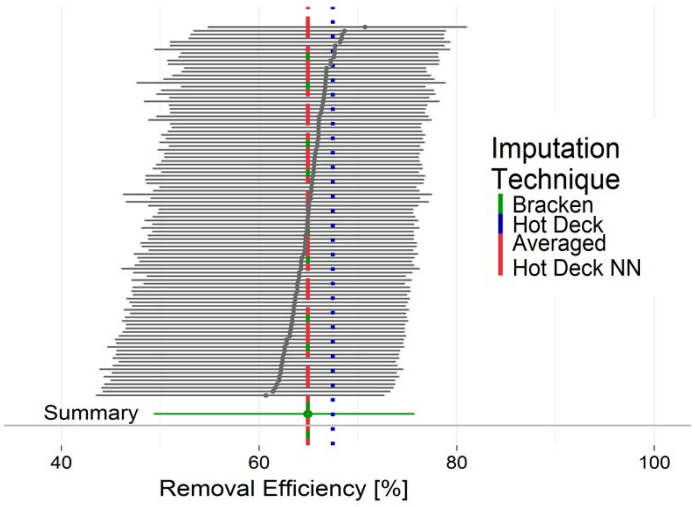

Figure 17 – Mean weighted removal efficiencies when the Hot Deck Nearest Neighbour (grey), the Hot Deck (blue), and the default Bracken (green) approaches were used to impute the missing standard deviations.

References

1. Lautz, L. S.; Struijs, J.; Nolte, T. M.; Breure, A. M.; van der Grinten, E.; van de Meent, D.; van Zelm, R., Evaluation of SimpleTreat 4.0: Simulations of pharmaceutical removal in wastewater treatment plant facilities. *Chemosphere* **2017,** *168*, 870-876.

2. Miege, C.; Choubert, J. M.; Ribeiro, L.; Eusebe, M.; Coquery, M., Fate of pharamaceuticals and personal care products in wastewater treatment plants. Conception of a database and first results. *Environmental pollution* **2009,** *157*, 1721-1726.

3. Oulton, R. L.; Kohn, T.; Cwiertny, D. M., Pharmaceuticals and personal care products in effluent matrices: A survey of transformation and removal during wastewater treatment and implications for wastewater management. *J Environ Monit* **2010,** *12* (11), 1956-78.

4. Verlicchi, P.; Al Aukidy, M.; Zambello, E., Occurrence of pharmaceutical compounds in urban wastewater: removal, mass load and environmental risk after a secondary treatment--a review. *The Science of the total environment* **2012,** *429*, 123-55.

5. Li, B.; Zhang, T., Mass flows and removal of antibiotics in two municipal wastewater treatment plants. *Chemosphere* **2011,** *83* (9), 1284-9.

6. Johnson, A. C.; Jurgens, M. D.; Nakada, N.; Hanamoto, S.; Singer, A. C.; Tanaka, H., Linking changes in antibiotic effluent concentrations to flow, removal and consumption in four different UK sewage treatment plants over four years. *Environmental pollution* **2017,** *220* (Pt B), 919-926.

7. Ifelebuegu, A. O., The fate and behavior of selected endocrine disrupting chemicals in full scale wastewater and sludge treatment unit processes. *International Journal of Environmental Science and Technology* **2011,** *8* (2), 245-254.

8. González, S.; Petrovic, M.; Barceló, D., Evaluation of two pilot scale membrane bioreactors for the elimination of selected surfactants from municipal wastewaters. *Journal of Hydrology* **2008,** *356* (1-2), 46-55.

9. Jelic, A.; Gros, M.; Ginebreda, A.; Cespedes-Sanchez, R.; Ventura, F.; Petrovic, M.; Barcelo, D., Occurrence, partition and removal of pharmaceuticals in sewage water and sludge during wastewater treatment. *Water research* **2011,** *45* (3), 1165-76.

10. Gomez, V.; Ferreres, L.; Pocurull, E.; Borrull, F., Determination of non-ionic and anionic surfactants in environmental water matrices. *Talanta* **2011,** *84* (3), 859-66.

11. Ghosh, G. C.; Okuda, T.; Yamashita, N.; Tanaka, H., Occurrence and eliminatin of antibiotics at four sewage treatment plants in Japan and their effects on bacterial ammonia oxidation. *Water Science and Technology* **2009,** *59* (4), 779-786.

12. Hozo, S. P.; Djulbegovic, B.; Hozo, I., Estimating the mean and variance from the median, range, and the size of a sample. *BMC Med Res Methodol* **2005,** *5*, 13.

13. Belhaj, D.; Jaabiri, I.; Ayadi, H.; Kallel, M.; Zhou, J. L., Occurrence and removal of steroidal estrogens in Centre Eastern Tunisia municipal sewage treatment plant. *Desalination and Water Treatment* **2013,** *52* (10-12), 2330-2339.

14. Bertanza, G.; Pedrazzani, R.; Dal Grande, M.; Papa, M.; Zambarda, V.; Montani, C.; Steimberg, N.; Mazzoleni, G.; Di Lorenzo, D., Effect of biological and chemical oxidation on the removal of estrogenic compounds (NP and BPA) from wastewater: an integrated assessment procedure. *Water research* **2011,** *45* (8), 2473-84.

15. Duan, Y. P.; Meng, X. Z.; Wen, Z. H.; Chen, L., Acidic pharmaceuticals in domestic wastewater and receiving water from hyper-urbanization city of China (Shanghai): environmental release and ecological risk. *Environ Sci Pollut Res Int* **2013,** *20* (1), 108-16.

16. Gonzalez, S.; Petrovic, M.; Barcelo, D., Removal of a broad range of surfactants from municipal wastewater--comparison between membrane bioreactor and conventional activated sludge treatment. *Chemosphere* **2007,** *67* (2), 335-43.

17. Jones, O. A.; Voulvoulis, N.; Lester, J. N., The occurrence and removal of selected pharmaceutical compounds in a sewage treatment works utilising activated sludge treatment. *Environmental pollution* **2007,** *145* (3), 738-44.

18. Kanda, R.; Griffin, P.; James, H. A.; Fothergill, J., Pharmaceutical and personal care products in sewage treatment works. *Journal of Environmental Monitoring* **2003,** *5* (5), 823.

19. Klaschka, U.; von der Ohe, P. C.; Bschorer, A.; Krezmer, S.; Sengl, M.; Letzel, M., Occurrences and potential risks of 16 fragrances in five German sewage treatment plants and their receiving waters. *Environ Sci Pollut Res Int* **2013,** *20* (4), 2456-71.

20. Kruglova, A.; Ahlgren, P.; Korhonen, N.; Rantanen, P.; Mikola, A.; Vahala, R., Biodegradation of ibuprofen, diclofenac and carbamazepine in nitrifying activated sludge under 12 degrees C temperature conditions. *The Science of the total environment* **2014,** *499*, 394-401.

21. Lindqvist, N.; Tuhkanen, T.; Kronberg, L., Occurrence of acidic pharmaceuticals in raw and treated sewages and in receiving waters. *Water research* **2005,** *39* (11), 2219-28.

22. Qi, W.; Singer, H.; Berg, M.; Muller, B.; Pernet-Coudrier, B.; Liu, H.; Qu, J., Elimination of polar micropollutants and anthropogenic markers by wastewater treatment in Beijing, China. *Chemosphere* **2015,** *119*, 1054-61.

23. Ren, Y.; Wei, K.; Liu, H.; Sui, G.; Wang, J.; Sun, Y.; Zheng, X., Occurrence and removal of selected polycyclic musks in two sewage treatment plants in Xi'an, China. *Frontiers of Environmental Science & Engineering* **2012,** *7* (2), 166-172.

24. Servos, M. R.; Bennie, D. T.; Burnison, B. K.; Jurkovic, A.; McInnis, R.; Neheli, T.; Schnell, A.; Seto, P.; Smyth, S. A.; Ternes, T. A., Distribution of estrogens, 17beta-estradiol and estrone, in Canadian municipal wastewater treatment plants. *The Science of the total environment* **2005,** *336* (1-3), 155-70.

25. Stumpf, M.; Ternes, T. A.; Wilken, R.-D.; Rodrigues, S. V.; Baumann, W., Polar drug residues in sewage and natural waters in the state of Rio de Janeiro, Brazil. *The Science of the total environment* **1999,** *225*, 135-141.

26. Tauxe-Wuersch, A.; De Alencastro, L. F.; Grandjean, D.; Tarradellas, J., Occurrence of several acidic drugs in sewage treatment plants in Switzerland and risk assessment. *Water research* **2005,** *39* (9), 1761-72.

27. Wang, D.; Sui, Q.; Lu, S. G.; Zhao, W. T.; Qiu, Z. F.; Miao, Z. W.; Yu, G., Occurrence and removal of six pharmaceuticals and personal care products in a wastewater treatment plant employing anaerobic/anoxic/aerobic and UV processes in Shanghai, China. *Environ Sci Pollut Res Int* **2014,** *21* (6), 4276-85.

28. Yasojima, M.; Nakada, N.; Komori, K.; Suzuki; Tanaka, H., Occurrence o flevofloxacin, clarithromycin and azithromycin in wastewater treatment plant in Japan. *Water Science and Technology* **2006,** *53* (11), 227-233.

29. Zhou, H.; Zhou, Y.; Li, H.; Wang, F., Fate and removal of selected endocrine-disrupting compounds in sewage using activated sludge treatment. *Water and Environment Journal* **2012,** *26* (4), 435-444.

30. Gatidou, G.; Thomaidis, N. S.; Stasinakis, A. S.; Lekkas, T. D., Simultaneous determination of the endocrine disrupting compounds nonylphenol, nonylphenol ethoxylates, triclosan and bisphenol A in wastewater and sewage sludge by gas chromatography-mass spectrometry. *J Chromatogr A* **2007,** *1138* (1-2), 32-41.

31. Struijs, J. *SimpleTreat 4.0: a model to predict the fate and emission of chemicals in wastewater treatment plants*; 2014.

32. Bossi, R.; Strand, J.; Sortkjaer, O.; Larsen, M. M., Perfluoroalkyl compounds in Danish wastewater treatment plants and aquatic environments. *Environment international* **2008,** *34* (4), 443-50.

33. Clara, M.; Scharf, S.; Scheffknecht, C.; Gans, O., Occurrence of selected surfactants in untreated and treated sewage. *Water research* **2007,** *41* (19), 4339-48.

34. Vallecillos, L.; Borrull, F.; Pocurull, E., An automated headspace solid-phasemicroextraction followed by gas chromatography-mass spectrometry method to determine macrocyclic musk fragrances in wastewater samples. *Analytical and bioanalytical chemistry* **2013,** *405* (29), 9547-54.

35. Clara, M.; Strenn, B.; Gans, O.; Martinez, E.; Kreuzinger, N.; Kroiss, H., Removal of selected pharmaceuticals, fragrances and endocrine disrupting compounds in a membrane bioreactor and conventional wastewater treatment plants. *Water research* **2005,** *39* (19), 4797-4807.

36. Clara, M.; Gans, O.; Windhofer, G.; Krenn, U.; Hartl, W.; Braun, K.; Scharf, S.; Scheffknecht, C., Occurrence of polycyclic musks in wastewater and receiving water bodies and fate during wastewater treatment. *Chemosphere* **2011,** *82* (8), 1116-1123.

37. Solé, M.; López de Alda, M. J.; Castillo, M.; Porte, C.; Ladegaard-Pedersen, K.; Barceló, D., Estrogenicity Determination in sewage treatment plants and surface waters from the Catalonian area (NE Spain). *Environmental Science and Technology* **2000,** *34*, 5076-5083.

38. Ain, S. Sewage treatment plant calculation. https://fr.slideshare.net/SharifahNurulAin/sewage-treatment-plant-design-calculation.

39. Benefield, L. A. *Rule development committee issue research report - Residential Flow Rates*; 2002.

40. Gujer, W., *Siedlungswasserwirtschaft*. 3rd ed.; Springer: 2006.

41. Kümmerer, K.; Steger-Hartmann, T.; Meyer, M., Biodegradability of the anti-tumor agent ifosfamide and its occurrence in hospital effluents and communal sewage. *Water research* **1997,** *31* (11), 2705-2710.

42. Abwasserzweckverband Breisgauer Bucht Virtueller Rundgang. https://www.azv-breisgau.de/index.php/klaeranlage/virtueller-rundgang (accessed 07.2017).

43. Kable Shatin sewage treatment works expansion, Hong Kong. http://www.water-technology.net/projects/shatin-stw/ (accessed 07.2017).

44. Kin-ping, I. Sewage treatment works in caverns - Hong Kong Experience. http://www.hkie.org.hk/hkiehkip/pdf/presentation/Day2/Ir%20IP%20Kin%20Ping.pdf (accessed 07.2017).

45. Manickum, T.; John, W., Occurrence, fate and environmental risk assessment of endocrine disrupting compounds at the wastewater treatment works in Pietermaritzburg (South Africa). *The Science of the total environment* **2014,** *468-469*, 584-97.

46. Umgeni Water Amanzi, Wastewater. 2014.

47. chinagate.cn Beijing Gaobeidian Wastewater Treatment Plant http://en.chinagate.cn/wastewater/2015-03/22/content_35123394.htm (accessed 07.2017).

48. Choi, K.; Kim, Y.; Park, J.; Park, C. K.; Kim, M.; Kim, H. S.; Kim, P., Seasonal variations of several pharmaceutical residues in surface water and sewage treatment plants of Han River, Korea. *The Science of the total environment* **2008,** *405* (1-3), 120-8.

49. Seoul Solution Tancheon Water Treatment Center. https://seoulsolution.kr/en/content/tancheon-water-treatment-center (accessed 07.2017).

50. Golovko, O.; Kumar, V.; Fedorova, G.; Randak, T.; Grabic, R., Seasonal changes in antibiotics, antidepressants/psychiatric drugs, antihistamines and lipid regulators in a wastewater treatment plant. *Chemosphere* **2014,** *111*, 418-26.

51. Hochtief České Budějovice, Sewage treatment plant Stages II and III. http://www.hochtief.cz/en/our-projects/reference-projects/ecological-and-water-management/ceske-budejovice-sewage-treatment-plant-stages-ii-and-iii.

52. Gulkowska, A.; Leung, H. W.; So, M. K.; Taniyasu, S.; Yamashita, N.; Yeung, L. W.; Richardson, B. J.; Lei, A. P.; Giesy, J. P.; Lam, P. K., Removal of antibiotics from wastewater by sewage treatment facilities in Hong Kong and Shenzhen, China. *Water research* **2008,** *42* (1-2), 395-403.

53. Komesli, O. T.; Muz, M.; Ak, M. S.; Bakırdere, S.; Gokcay, C. F., Occurrence, fate and removal of endocrine disrupting compounds (EDCs) in Turkish wastewater treatment plants. *Chemical Engineering Journal* **2015,** *277*, 202-208.

54. Ankara Metropolitan Municipality Tatlar Wastewater Treatment Plant. http://www.aski.gov.tr/en/Icerik.aspx?detay=821&id=817 (accessed 07.2017).

55. Bendz, D.; Paxeus, N. A.; Ginn, T. R.; Loge, F. J., Occurrence and fate of pharmaceutically active compounds in the environment, a case study: Hoje River in Sweden. *J Hazard Mater* **2005,** *122* (3), 195-204.

56. VASYD *Källby Wastewater Treatment Plant*; VASYD,.

57. Miljøministeriet *Punktkilder 2006, Det nationale program for overvågning af*

vandmiljøet; Fagdatacenterrapport; 2007.

58. Bahlmann, A.; Brack, W.; Schneider, R. J.; Krauss, M., Carbamazepine and its metabolites in wastewater: Analytical pitfalls and occurrence in Germany and Portugal. *Water research* **2014,** *57*, 104-14.

59. Berliner Wasserbetriebe Berliner Wasserbetriebe. (accessed 07.2017).

60. Agència Catalana de l'Aigua Depuradores en servei. http://aca-web.gencat.cat/aca/appmanager/aca/aca?_nfpb=true&_pageLabel=P122555446120820154008 4 (accessed 07.2017).

61. Ort, C.; Lawrence, M. G.; Rieckermann, J.; Joss, A., Sampling for pharmaceuticals and personal care products (PPCPs) and illicit drugs in wastewater systems: are your conclusions valid? A critical review. *Environmental Science and Technology* **2010,** *44*, 6024-6035.

62. Sablijc, A.; Güsten, H.; Verhaar, H.; Hermens, J., QSAR Modelling of soil sorption. Improvements and systematics of log KOC vs. log KOW correlations. *Chemosphere* **1995,** *31*, 4489-4514.

63. Franco, A.; Trapp, S., Estimation of the soil-water partition coefficient normalized to organic carbon for ionizable organic chemicals. *Environmental Toxicology and Chemistry* **2008,** *27* (10), 1995-2004.

64. ECETOC *Environmental Risk Assessment of Ionisable Organic Compounds*; 123; European Centre for Ecotoxicology and Toxicology of Chemicals,: Belgium, 2013.

65. EPA *5. Estimating Physical / Chemical and Environmental Fate Properties with EPI Suite*; U.S. Environmental Protection Agency: 2015.

66. Warhurst, A. M. *An environmental assessment of alkyphenol ehoxylates and alkylphenols*; Friends of the Earth, Scotland: 1995.

67. Arvaniti, O. S.; Ventouri, E. I.; Stasinakis, A. S.; Thomaidis, N. S., Occurrence of different classes of perfluorinated compounds in Greek wastewater treatment plants and determination of their solid-water distribution coefficients. *J Hazard Mater* **2012,** *239-240*, 24-31.

68. Szabó, Z.; Szoboszlai, N.; Jámbor, É.; Gulyás, G.; Lóránd, T.; Ohmacht, R.; Záray, G.; Mihucz, V. G., Determination of four dipyrone metabolites in Hungarian municipal wastewater by liquid chromatography mass spectrometry. *Microchemical Journal* **2013,** *107*, 152-157.

69. Wikipedia https://www.wikipedia.org/.

70. Ternes, T. A.; Kreckel, P.; Mueller, J., Behaviour and occurrence of estrogens in municipal sewage treatment plants — II. Aerobic batch experiments with activated sludge. *Science of The Total Environment* **1999,** *225* (1–2), 91-99.

71. Cerilliant O-Desmethylvenlafaxine. https://www.cerilliant.com/shopOnline/Item_Details.aspx?itemno=3210edc1-da8a-40ad-b95a-af92a96a6066 (accessed 06).

72. DrugBank Seproxetine. https://www.drugbank.ca/drugs/DB06731 (accessed 06).

73. Kasprzyk-Hordern, B.; Dinsdale, R. M.; Guwy, A. J., The removal of pharmaceuticals, personal care products, endocrine disruptors and illicit drugs during wastewater treatment and its impact on the quality of receiving waters. *Water research* **2009,** *43* (2), 363-80.

74. Larsson, E.; al-Hamimi, S.; Jonsson, J. A., Behaviour of nonsteroidal anti-inflammatory drugs and eight of their metabolites during wastewater treatment studied by hollow fibre liquid phase microextraction and liquid chromatography mass spectrometry. *The Science of the total environment* **2014,** *485-486*, 300-8.

75. Aymerich, I.; Acuna, V.; Barcelo, D.; Garcia, M. J.; Petrovic, M.; Poch, M.; Rodriguez-Mozaz, S.; Rodriguez-Roda, I.; Sabater, S.; von Schiller, D.; Corominas, L., Attenuation of pharmaceuticals and their transformation products in a wastewater treatment plant and its receiving river ecosystem. *Water research* **2016,** *100*, 126-36.

76. López-Muñoz, F.; Álamo, C., Active metabolites as antidepressant drugs: the role of norquetiapine in the mechanism of action of quetiapine in the treatment of mood disorders. *Frontiers in psychiatry* **2013,** *4*, 102.

77. HMDB Showing metabocard for dehydronifedipine (HMDB61041). http://www.hmdb.ca/metabolites/HMDB61041 (accessed 06).

78. Sigma-Aldrich Amitriptyline metabolite, (±)-E-10-hydroxylated-. http://www.sigmaaldrich.com/catalog/product/sial/a115?lang=en&region=NL (accessed 6).

79. Cayman Epitetracycline (hydrochloride). https://www.caymanchem.com/product/19470 (accessed 6).

80. Feijtel, T. C. J.; Boeije, G.; Matthies, M.; Young, A.; Morris, G.; Gandolfi, C.; Hansen, B.; Fox, K.; Holt, M.; Koch, V.; Schroder, R.; Cassani, G.; Schowanek, D.; Rosenblom, J.; Niessen, H., Development of a geography-referenced regional exposure assessment tool for european rivers - GREAT-ER Contribution to GREAT-ER #1. *Chemosphere* **1997,** *34* (11), 2351-2373.

81. Li, H.-Q.; Jiku, F.; Schröder, H. F., Assessment of the pollutant elimination efficiency by chromatography/mass spectrometry, liquid chromatography-mass spectrometry and -tandem mass spectrometry Comparison of conventional and membrane-assisted biological wastewater treatment processes. . *Journal of Chromatography,* **2000,** *889*, 155-176.

82. Sabaliunas, D.; Webb, S. F.; Hauk, A.; Jacob, M.; Eckhoff, W. S., Environmental fate of Triclosan in the River Aire Basin, UK. *Water research* **2003,** *37* (13), 3145-3154.

83. Holt, M. S.; Waters, J.; Comber, M. H. I.; Armitage, R.; Morris, G.; Newbery, C., AIS/CESIO environmental surfactant monitoring programme. SDIA sewage treatment pilot study on linear alkylbenzene sulphonate (LAS). *Water research* **1995,** *29* (9), 2063-2070.

84. Gomez, M. J.; Martinez Bueno, M. J.; Lacorte, S.; Fernandez-Alba, A. R.; Aguera, A., Pilot survey monitoring pharmaceuticals and related compounds in a sewage treatment plant located on the Mediterranean coast. *Chemosphere* **2007,** *66* (6), 993-1002.

85. Gori, R. C., Laura; Petrovic, M.; Gonzalez, S.; Barcelò, D.; Lubello, C.; Malpei, F., Fate of surfactants in membrane bioreacors and conventional activated sludge plants. *Environmental Science and Technology* **2010,** *44*, 8223-8229.

86. Pirsaheb, M.; Khamutian, R.; Khodadadian, M., A comparison between extended aeration sludge and conventional activated sludge treatment for removal of linear alkylbenzene sulfonates (Case study: Kermanshah and Paveh WWTP). *Desalination and Water Treatment* **2013,** *52* (25-27), 4673-4680.

87. Artola-Garciano, E.; Borkent, I.; Hermens, J. L. M.; Vaes, W. H. J., Removal of two polycyclic musks in sewage treatment plantsö freelz dissolved and total concentrations. *Environmental Science and Technology* **2003,** *37*, 3111-3116.

88. Berset, J. D.; Kupper, T.; Etter, R.; Tarradellas, J., Considerations about the enantioselective transformation of polycyclic musks in wastewater, treated wastewater and sewage sludge and analysis of their fate in a sequencing batch reactor plant. *Chemosphere* **2004,** *57* (8), 987-96.

89. Bester, K., Retention characteristics and balance assessment for two polycyclic musk fragrances (HHCB and AHTN) in a typical German sewage treatment plant. *Chemosphere* **2004,** *57* (8), 863-70.

90. Carballa, M.; Omil, F.; Lema, J. M.; Llompart, M.; Garcia-Jares, C.; Rodriguez, I.; Gomez, M.; Ternes, T., Behavior of pharmaceuticals, cosmetics and hormones in a sewage treatment plant. *Water research* **2004,** *38* (12), 2918-26.

91. Chen, D.; Zeng, X.; Sheng, Y.; Bi, X.; Gui, H.; Sheng, G.; Fu, J., The concentrations and distribution of polycyclic musks in a typical cosmetic plant. *Chemosphere* **2007,** *66* (2), 252-8.

92. Dsikowitzky, L.; Schwarzbauer, J.; Littke, R., Distribution of polycyclic musks in water and particulate matter of the Lippe River (Germany). *Organic Geochemistry* **2002,** *33*, 1747-1758.

93. Godayol, A.; Besalu, E.; Antico, E.; Sanchez, J. M., Monitoring of sixteen fragrance allergens and two polycyclic musks in wastewater treatment plants by solid phase microextraction coupled to gas chromatography. *Chemosphere* **2015,** *119*, 363-70.

94. He, Y. J.; Chen, W.; Zheng, X. Y.; Wang, X. N.; Huang, X., Fate and removal of typical pharmaceuticals and personal care products by three different treatment processes. *The Science of the total environment* **2013,** *447*, 248-54.

95. Horii, Y.; Reiner, J. L.; Loganathan, B. G.; Senthil Kumar, K.; Sajwan, K.; Kannan, K., Occurrence and fate of polycyclic musks in wastewater treatment plants in Kentucky and Georgia, USA. *Chemosphere* **2007,** *68* (11), 2011-20.

96. Kupper, T.; Plagellat, C.; Brandli, R. C.; de Alencastro, L. F.; Grandjean, D.; Tarradellas, J., Fate and removal of polycyclic musks, UV filters and biocides during wastewater treatment. *Water research* **2006,** *40* (14), 2603-12.

97. Reiner, J. L.; Berset, J. D.; Kannan, K., Mass flow of polycyclic musks in two wastewater treatment plants. *Arch Environ Contam Toxicol* **2007,** *52* (4), 451-7.

98. Rosal, R.; Rodriguez, A.; Perdigon-Melon, J. A.; Petre, A.; Garcia-Calvo, E.; Gomez, M. J.; Aguera, A.; Fernandez-Alba, A. R., Occurrence of emerging pollutants in urban wastewater and their removal through biological treatment followed by ozonation. *Water research* **2010,** *44* (2), 578-88.

99. Salgado, R.; Marques, R.; Noronha, J. P.; Carvalho, G.; Oehmen, A.; Reis, M. A., Assessing the removal of pharmaceuticals and personal care products in a full-scale activated sludge plant. *Environ Sci Pollut Res Int* **2012,** *19* (5), 1818-27.

100. Simonich, S. L.; Begley, W. M.; Debaere, G.; Eckhoff, W. S., Trace analysis of fragrance material in wastewater and treated wastewater. *Environmental Science and Technology* **2000,** *34*, 959-965.

101. Smyth, S. A.; Lishman, L.; McBean, E. A.; Kleywegt, S.; Yang, J. J.; Svoboda, M. L.; Ormonde, S.; Pileggi, V.; Lee, H.-B.; Seto, P., Polycyclic and nitro musks in Canadian municipal wastewater: occurrence and removal in wastewater treatment. *Water Quality Research Journal Canada* **2007,** *42* (3), 138-152.

102. Ternes, T. A.; Bonerz, M.; Herrmann, N.; Teiser, B.; Andersen, H. R., Irrigation of treated wastewater in Braunschweig, Germany: an option to remove pharmaceuticals and musk fragrances. *Chemosphere* **2007,** *66* (5), 894-904.

103. Yang, J. J.; Metcalfe, C. D., Fate of synthetic musks in a domestic wastewater treatment plant and in an agricultural field amended with biosolids. *The Science of the total environment* **2006,** *363* (1-3), 149-65.

104. Zeng, X.; Sheng, G.; Gui, H.; Chen, D.; Shao, W.; Fu, J., Preliminary study on the occurrence and distribution of polycyclic musks in a wastewater treatment plant in Guandong, China. *Chemosphere* **2007,** *69* (8), 1305-11.

105. Zhou, H.; Huang, X.; Gao, M.; Wang, X.; Wen, X., Distribution and elimination of polycyclic musks in three sewage treatment plants of Beijing, China. *Journal of Environmental Sciences* **2009,** *21* (5), 561-567.

106. Alder, A. C.; Schaffner, C.; Majewsky, M.; Klasmeier, J.; Fenner, K., Fate of beta-blocker human pharmaceuticals in surface water: comparison of measured and simulated concentrations in the Glatt Valley Watershed, Switzerland. *Water research* **2010,** *44* (3), 936-48.

107. Andersen, H.; Siegrist, H.; Halling-Sorensen, B.; Ternes, T., Fate of estrogens in a municipal sewage treatment plant. *Environmental Science and Technology* **2003,** *37* (18), 4021-4026.

108. Baronti, C.; Curini, R.; D'Ascenzo, G.; di Corcia, A.; Gentili, A.; Samperi, R., Monitoring natural and synthetic estrogens at activated sludge sewage treatment plants and in a receiving river water. *Environmental Science and Technology* **2000,** *34* (24), 5059-5066.

109. Batt, A. L.; Kim, S.; Aga, D. S., Enhanced Biodegradation of iopromide and trimethoprim in nitrifying activated sludge. *Environmental Science and Technology* **2006,** *40*, 7367-7373.

110. Batt, A. L.; Kim, S.; Aga, D. S., Comparison of the occurrence of antibiotics in four full-scale wastewater treatment plants with varying designs and operations. *Chemosphere* **2007,** *68* (3), 428-35.

111. Bijlsma, L.; Emke, E.; Hernandez, F.; de Voogt, P., Investigation of drugs of abuse and relevant metabolites in Dutch sewage water by liquid chromatography coupled to high resolution mass spectrometry. *Chemosphere* **2012,** *89* (11), 1399-1406.

112. Birosova, L.; Mackulak, T.; Bodik, I.; Ryba, J.; Skubak, J.; Grabic, R., Pilot study of seasonal occurrence and distribution of antibiotics and drug resistant bacteria in wastewater treatment plants in Slovakia. *The Science of the total environment* **2014,** *490*, 440-4.

113. Blair, B. D.; Crago, J. P.; Hedman, C. J.; Treguer, R. J.; Magruder, C.; Royer, L. S.; Klaper, R. D., Evaluation of a model for the removal of pharmaceuticals, personal care products, and hormones from wastewater. *The Science of the total environment* **2013,** *444*, 515-21.

114. Bollmann, A. F.; Seitz, W.; Prasse, C.; Lucke, T.; Schulz, W.; Ternes, T., Occurrence and fate of amisulpride, sulpiride, and lamotrigine in municipal wastewater treatment plants with biological treatment and ozonation. *J Hazard Mater* **2016,** *320*, 204-215.

115. Braga, O.; Smythe, G. A.; Schäfer, A. I.; Feitz, A. J., Fate of steroid estrogens in australian inland and coastal wastewater treatment plants. *Environmental Science and Technology* **2005,** *39*, 3351-3358.

116. Camacho-Muñoz, D.; Martín, J.; Santos, J. L.; Aparicio, I.; Alonso, E., Effectiveness of Conventional and Low-Cost Wastewater Treatments in the Removal of Pharmaceutically Active Compounds. *Water, Air, & Soil Pollution* **2011,** *223* (5), 2611-2621.

117. Celiz, M. D.; Pérez, S.; Barcelo, D.; Aga, D. S., Trace analysis of polar pharmaceuticals in wastewater by LC-MS-MS: Comparison of membrane bioreactor and activated sludge systems. *Journal of Chromatographic Science* **2009,** *47*, 19-25.

118. Chang, H.; Hu, J.; Shao, B., Occurrence of natural and synthetic glucocorticoids in sewage treatment plants and receiving river waters. *Environmental Science and Technology* **2007,** *41*, 3462-3468.

119. Collado, N.; Rodriguez-Mozaz, S.; Gros, M.; Rubirola, A.; Barcelo, D.; Comas, J.; Rodriguez-Roda, I.; Buttiglieri, G., Pharmaceuticals occurrence in a WWTP with significant industrial contribution and its input into the river system. *Environmental pollution* **2014,** *185*, 202-12.

120. Drewes, J. E.; Hemming, J.; Ladenburger, S. J.; Schauer, J.; William, S., An assessment of endocrine disrupting activity changes during wastewater treatment through the use of bioassays and chemical measurements. *Water Environment Research* **2005,** *77* (1).

121. Estrada-Arriaga, E. B.; Cortes-Munoz, J. E.; Gonzalez-Herrera, A.; Calderon-Molgora, C. G.; de Lourdes Rivera-Huerta, M.; Ramirez-Camperos, E.; Montellano-Palacios, L.; Gelover-Santiago, S. L.; Perez-Castrejon, S.; Cardoso-Vigueros, L.; Martin-Dominguez, A.; Garcia-Sanchez, L., Assessment of full-scale biological nutrient removal systems upgraded with physico-chemical processes for the removal of emerging pollutants present in wastewaters from Mexico. *The Science of the total environment* **2016,** *571*, 1172-82.

122. Evans, S. E.; Davies, P.; Lubben, A.; Kasprzyk-Hordern, B., Determination of chiral pharmaceuticals and illicit drugs in wastewater and sludge using microwave assisted extraction, solid-phase extraction and chiral liquid chromatography coupled with tandem mass spectrometry. *Anal Chim Acta* **2015,** *882*, 112-26.

123. Froehner, S.; Piccioni, W.; Machado, K. S.; Aisse, M. M., Removal Capacity of Caffeine, Hormones, and Bisphenol by Aerobic and Anaerobic Sewage Treatment. *Water, Air, & Soil Pollution* **2010,** *216* (1-4), 463-471.

124. Gagnon, C.; Lajeunesse, A., Low removal of acidic and hydrophilic pharmaceutical products by various types of municipal wastewater treatment plants. *Journal of Xenobiotics* **2012,** *2* (1), 3.

125. Gao, P.; Ding, Y.; Li, H.; Xagoraraki, I., Occurrence of pharmaceuticals in a municipal wastewater treatment plant: mass balance and removal processes. *Chemosphere* **2012,** *88* (1), 17-24.

126. Gardner, M.; Jones, V.; Comber, S.; Scrimshaw, M. D.; Coello-Garcia, T.; Cartmell, E.; Lester, J.; Ellor, B., Performance of UK wastewater treatment works with respect to trace contaminants. *The Science of the total environment* **2013,** *456-457*, 359-69.

127. Gracia-Lor, E.; Sancho, J. V.; Serrano, R.; Hernandez, F., Occurrence and removal of pharmaceuticals in wastewater treatment plants at the Spanish Mediterranean area of Valencia. *Chemosphere* **2012,** *87* (5), 453-462.

128. Guerra, P.; Kim, M.; Shah, A.; Alaee, M.; Smyth, S. A., Occurrence and fate of antibiotic, analgesic/anti-inflammatory, and antifungal compounds in five wastewater treatment processes. *The Science of the total environment* **2014,** *473-474*, 235-43.

129. Gurke, R.; Rossler, M.; Marx, C.; Diamond, S.; Schubert, S.; Oertel, R.; Fauler, J., Occurrence and removal of frequently prescribed pharmaceuticals and corresponding metabolites in wastewater of a sewage treatment plant. *The Science of the total environment* **2015,** *532*, 762-70.

130. Gurke, R.; Rossmann, J.; Schubert, S.; Sandmann, T.; Rossler, M.; Oertel, R.; Fauler, J., Development of a SPE-HPLC-MS/MS method for the determination of most prescribed pharmaceuticals and related metabolites in urban sewage samples. *J Chromatogr B Analyt Technol Biomed Life Sci* **2015,** *990*, 23-30.

131. Hijosa-Valsero, M.; Matamoros, V.; Martin-Villacorta, J.; Becares, E.; Bayona, J. M., Assessment of full-scale natural systems for the removal of PPCPs from wastewater in small communities. *Water research* **2010,** *44* (5), 1429-39.

132. Hollender, J.; Zimmermann, S. G.; Koepke, S.; Krauss, M.; McArdell, C. S.; Ort, C.; Singer, H.; von Gunten, U.; Siegrist, H., Elimination of organic micropollutants in a municipal wastewater treatment plant upgraded with a full-scale post-ozonation followed by sand filtration. *Environmental Science and Technology* **2009,** *43* (7862-7869).

133. Joss, A.; Andersen, H.; Ternes, T.; Richle, P. R.; Siegrist, H., Removal of estrogens in municipal wastewater treatment under aerobic and anaerobic conditions: consequences for plant optimization. *Environmental Science and Technology* **2004,** *38*, 3047-3055.

134. Joss, A.; Keller, E.; Alder, A. C.; Gobel, A.; McArdell, C. S.; Ternes, T.; Siegrist, H., Removal of pharmaceuticals and fragrances in biological wastewater treatment. *Water research* **2005,** *39* (14), 3139-52.

135. Karthikeyan, K. G.; Meyer, M. T., Occurrence of antibiotics in wastewater treatment facilities in Wisconsin, USA. *The Science of the total environment* **2006,** *361* (1-3), 196-207.

136. Kimura, K.; Hara, H.; Watanabe, Y., Elimination of selected acidic pharmaceuticals from municipal wastewater by an activated sludge system and membrane bioreactors. *Environmental Science and Technology* **2007,** *41*, 3708-3714.

137. Lajeunesse, A.; Smyth, S. A.; Barclay, K.; Sauve, S.; Gagnon, C., Distribution of antidepressant residues in wastewater and biosolids following different treatment processes by municipal wastewater treatment plants in Canada. *Water research* **2012,** *46* (17), 5600-12.

138. Leclercq, M.; Mathieu, O.; Gomez, E.; Casellas, C.; Fenet, H.; Hillaire-Buys, D., Presence and fate of carbamazepine, oxcarbazepine, and seven of their metabolites at wastewater treatment plants. *Arch Environ Contam Toxicol* **2009,** *56* (3), 408-15.

139. Leung, H. W.; Minh, T. B.; Murphy, M. B.; Lam, J. C.; So, M. K.; Martin, M.; Lam, P. K.; Richardson, B. J., Distribution, fate and risk assessment of antibiotics in sewage treatment plants in Hong Kong, South China. *Environment international* **2012,** *42*, 1-9.

140. Lindberg, R. H.; Wennberg, P.; Johansson, M. I.; Tysklind, M.; Andersson, B. A. V., Screening of human antibiotic substances and determination of weekly mass flows in five sewage treatment plants in Sweden. *Environmental Science and Technology* **2005,** *39* (10), 3421-3429.

141. Loganathan, B.; Phillips, M.; Mowery, H.; Jones-Lepp, T. L., Contamination profiles and mass loadings of macrolide antibiotics and illicit drugs from a small urban wastewater treatment plant. *Chemosphere* **2009,** *75* (1), 70-7.

142. Mackulak, T.; Mosny, M.; Skubak, J.; Grabic, R.; Birosova, L., Fate of psychoactive compounds in wastewater treatment plant and the possibility of their degradation using aquatic plants. *Environ Toxicol Pharmacol* **2015,** *39* (2), 969-73.

143. Martin, J.; Camacho-Munoz, D.; Santos, J. L.; Aparicio, I.; Alonso, E., Occurrence of pharmaceutical compounds in wastewater and sludge from wastewater treatment plants: removal and ecotoxicological impact of wastewater discharges and sludge disposal. *J Hazard Mater* **2012,** *239-240*, 40-7.

144. Matongo, S.; Birungi, G.; Moodley, B.; Ndungu, P., Pharmaceutical residues in water and sediment of Msunduzi River, KwaZulu-Natal, South Africa. *Chemosphere* **2015,** *134*, 133-40.

145. Metcalfe, C. D.; Koenig, B. G.; Bennie, D. T.; Servos, M.; Ternes, T.; Hirsch, R., Occurrence of neutral and acidic drugs in the effluents of Canadian sewage treatment plants. *Environmental Toxicology and Chemistry* **2003,** *22* (12), 2872-2880.

146. Morasch, B.; Bonvin, F.; Reiser, H.; Grandjean, D.; de Alencastro, L. F.; Perazzolo, C.; Chevre, N.; Kohn, T., Occurrence and fate of micropollutants in the Vidy Bay of Lake Geneva, Switzerland. Part II: micropollutant removal between wastewater and raw drinking water. *Environ Toxicol Chem* **2010,** *29* (8), 1658-68.

147. Nakada, N.; Tanishima, T.; Shinohara, H.; Kiri, K.; Takada, H., Pharmaceutical chemicals and endocrine disrupters in municipal wastewater in Tokyo and their removal during activated sludge treatment. *Water research* **2006,** *40* (17), 3297-303.

148. Nie, Y.; Qiang, Z.; Zhang, H.; Ben, W., Fate and seasonal variation of endocrine-disrupting chemicals in a sewage treatment plant with A/A/O process. *Separation and Purification Technology* **2012,** *84*, 9-15.

149. Oliveira, T. S.; Murphy, M.; Mendola, N.; Wong, V.; Carlson, D.; Waring, L., Characterization of Pharmaceuticals and Personal Care products in hospital effluent and waste water influent/effluent by direct-injection LC-MS-MS. *The Science of the total environment* **2015,** *518-519*, 459-78.

150. Papageorgiou, M.; Kosma, C.; Lambropoulou, D., Seasonal occurrence, removal, mass loading and environmental risk assessment of 55 pharmaceuticals and personal care products in a municipal wastewater treatment plant in Central Greece. *The Science of the total environment* **2016,** *543* (Pt A), 547-69.

151. Patrolecco, L.; Capri, S.; Ademollo, N., Occurrence of selected pharmaceuticals in the principal sewage treatment plants in Rome (Italy) and in the receiving surface waters. *Environ Sci Pollut Res Int* **2015,** *22* (8), 5864-76.

152. Pereira, A. M.; Silva, L. J.; Meisel, L. M.; Lino, C. M.; Pena, A., Environmental impact of pharmaceuticals from Portuguese wastewaters: geographical and seasonal occurrence, removal and risk assessment. *Environ Res* **2015,** *136*, 108-19.

153. Radjenovic, J.; Petrovic, M.; Barcelo, D., Fate and distribution of pharmaceuticals in wastewater and sewage sludge of the conventional activated sludge (CAS) and advanced membrane bioreactor (MBR) treatment. *Water research* **2009,** *43* (3), 831-41.

154. Repice, C.; Dal Grande, M.; Maggi, R.; Pedrazzani, R., Licit and illicit drugs in a wastewater treatment plant in Verona, Italy. *The Science of the total environment* **2013,** *463-464*, 27-34.

155. Rodríguez, I.; Quintana, J. B.; Carpinteiro, J.; Carro, A. M.; Lorenzo, R. A.; Cela, R., Determination of acidic drugs in sewage water by gas chromatography - mass spectrometry as tert.-butyldimethylsilyl derivatives. *Journal of Chromatography,* **2003,** *985*, 265-274.

156. Rubirola, A.; Llorca, M.; Rodriguez-Mozaz, S.; Casas, N.; Rodriguez-Roda, I.; Barcelo, D.; Buttiglieri, G., Characterization of metoprolol biodegradation and its transformation products generated in activated sludge batch experiments and in full scale WWTPs. *Water research* **2014,** *63*, 21-32.

157. Ryu, J.; Oh, J.; Snyder, S. A.; Yoon, Y., Determination of micropollutants in combined sewer overflows and their removal in a wastewater treatment plant (Seoul, South Korea). *Environ Monit Assess* **2014,** *186* (5), 3239-51.

158. Samaras, V. G.; Stasinakis, A. S.; Mamais, D.; Thomaidis, N. S.; Lekkas, T. D., Fate of selected pharmaceuticals and synthetic endocrine disrupting compounds during wastewater treatment and sludge anaerobic digestion. *J Hazard Mater* **2013,** *244-245*, 259-67.

159. Santos, J. L.; Aparicio, I.; Alonso, E., Occurrence and risk assessment of pharmaceutically active compounds in wastewater treatment plants. A case study: Seville city (Spain). *Environment international* **2007,** *33* (4), 596-601.

160. Santos, J. L.; Aparicio, I.; Callejon, M.; Alonso, E., Occurrence of pharmaceutically active compounds during 1-year period in wastewaters from four wastewater treatment plants in Seville (Spain). *J Hazard Mater* **2009,** *164* (2-3), 1509-16.

161. Sari, S.; Ozdemir, G.; Yangin-Gomec, C.; Zengin, G. E.; Topuz, E.; Aydin, E.; Pehlivanoglu-Mantas, E.; Okutman Tas, D., Seasonal variation of diclofenac concentration and its relation with wastewater

characteristics at two municipal wastewater treatment plants in Turkey. *J Hazard Mater* **2014,** *272*, 155-64.

162. Schlusener, M. P.; Hardenbicker, P.; Nilson, E.; Schulz, M.; Viergutz, C.; Ternes, T. A., Occurrence of venlafaxine, other antidepressants and selected metabolites in the Rhine catchment in the face of climate change. *Environmental pollution* **2015,** *196*, 247-56.

163. Senta, I.; Terzic, S.; Ahel, M., Occurrence and fate of dissolved and particulate antimicrobials in municipal wastewater treatment. *Water research* **2013,** *47* (2), 705-14.

164. Shao, X.-L.; Ma, J., Fate and mass balance of 13 kinds of endocrine disrupting chemicals in a sewage treatment plant. *IEEE* **2009**, 1-4.

165. Stasinakis, A. S.; Thomaidis, N. S.; Arvaniti, O. S.; Asimakopoulos, A. G.; Samaras, V. G.; Ajibola, A.; Mamais, D.; Lekkas, T. D., Contribution of primary and secondary treatment on the removal of benzothiazoles, benzotriazoles, endocrine disruptors, pharmaceuticals and perfluorinated compounds in a sewage treatment plant. *The Science of the total environment* **2013,** *463-464*, 1067-75.

166. Subedi, B.; Kannan, K., Occurrence and fate of select psychoactive pharmaceuticals and antihypertensives in two wastewater treatment plants in New York State, USA. *The Science of the total environment* **2015,** *514*, 273-80.

167. Thomas, P. M.; Foster, G. D., Determination of Nonsteroidal Anti-inflammatory Drugs, Caffeine, and Triclosan in Wastewaterby Gas Chromatography–Mass Spectrometry. *Journal of Environmental Science and Health, Part A* **2004,** *39* (8), 1969-1978.

168. Vergeynst, L.; Haeck, A.; De Wispelaere, P.; Van Langenhove, H.; Demeestere, K., Multi-residue analysis of pharmaceuticals in wastewater by liquid chromatography-magnetic sector mass spectrometry: method quality assessment and application in a Belgian case study. *Chemosphere* **2015,** *119 Suppl*, S2-8.

169. Vieno, N. M.; Tuhkanen, T.; Kronberg, L., Seasonal variation in the occurrence of pharmaceuticals in effluents from a sewage treatment plant and in the recipient water. *Environmental Science and Technology* **2005,** *39*, 8220-8226.

170. Watkinson, A. J.; Murby, E. J.; Costanzo, S. D., Removal of antibiotics in conventional and advanced wastewater treatment: implications for environmental discharge and wastewater recycling. *Water research* **2007,** *41* (18), 4164-76.

171. Wick, A.; Fink, G.; Joss, A.; Siegrist, H.; Ternes, T. A., Fate of beta blockers and psycho-active drugs in conventional wastewater treatment. *Water research* **2009,** *43* (4), 1060-74.

172. Xu, W.; Zhang, G.; Li, X.; Zou, S.; Li, P.; Hu, Z.; Li, J., Occurrence and elimination of antibiotics at four sewage treatment plants in the Pearl River Delta (PRD), South China. *Water research* **2007,** *41* (19), 4526-34.

173. Yan, Q.; Gao, X.; Chen, Y. P.; Peng, X. Y.; Zhang, Y. X.; Gan, X. M.; Zi, C. F.; Guo, J. S., Occurrence, fate and ecotoxicological assessment of pharmaceutically active compounds in wastewater and sludge from wastewater treatment plants in Chongqing, the Three Gorges Reservoir Area. *The Science of the total environment* **2014,** *470-471*, 618-30.

174. Yu, C. P.; Chu, K. H., Occurrence of pharmaceuticals and personal care products along the West Prong Little Pigeon River in east Tennessee, USA. *Chemosphere* **2009,** *75* (10), 1281-6.

175. Yuan, X.; Qiang, Z.; Ben, W.; Zhu, B.; Qu, J., Distribution, mass load and environmental impact of multiple-class pharmaceuticals in conventional and upgraded municipal wastewater treatment plants in East China. *Environmental science. Processes & impacts* **2015,** *17* (3), 596-605.

176. Zorita, S.; Martensson, L.; Mathiasson, L., Occurrence and removal of pharmaceuticals in a municipal sewage treatment system in the south of Sweden. *The Science of the total environment* **2009,** *407* (8), 2760-70.

177. Camacho-Muñoz, D.; Martín, J.; Santos, J. L.; Aparicio, I.; Alonso, E., Occurrence of surfactants in wastewater: hourly and seasonal variations in urban and industrial wastewaters from Seville (Southern Spain). *Science of the Total Environment* **2014,** *468*, 977-984.

178. Matthijs, E.; Holt, M. S.; Kiewiet, A.; Rijs, G. B. J., Environmental monitoring for linear alkylbenzene sulfonate, alcohol ethoxylate, alcohol ethoxy sulfate, alcohol sulfate, and soap. *Environmental Toxicology and Chemistry* **1999,** *18* (11), 2634-2644.

179. McAvoy, D.; Dyer, S. D.; Fendinger, N. J.; Eckhoff, W. S.; Lawrence, D. L.; Begley, W. M., Removal of alcohol Ethoxylates, alkyl ethodylate sulfates, and linear alkylbenzene sulfonates in wastewater treatment. *Environmental Toxicology and Chemistry* **1998,** *17* (9), 1705-1711.

180. Zuur, A.; Ieno, E.; Walker, N.; Saveliev, A.; Smith, G., Mixed effects models and extensions in ecology with R. New York: Springer. 2009.