



HAL
open science

Fate of pharmaceuticals and personal care products in wastewater treatment plants. Conception of a database and first results

Cecile Miege, J.M. Choubert, L. Ribeiro, M. Eusebe, Marina Coquery

► To cite this version:

Cecile Miege, J.M. Choubert, L. Ribeiro, M. Eusebe, Marina Coquery. Fate of pharmaceuticals and personal care products in wastewater treatment plants. Conception of a database and first results. *Environmental Pollution*, 2009, 157, p. 1721 - p. 1726. 10.1016/j.envpol.2008.11.045 . hal-00455347

HAL Id: hal-00455347

<https://hal.science/hal-00455347>

Submitted on 10 Feb 2010

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Fate of pharmaceuticals and personal care products in wastewater treatment plants - Conception of a database and first results

C. Miège, J.M. Choubert, L. Ribeiro, M. Eusèbe, M. Coquery

Cemagref, Water Quality and Pollution Control Research Unit, 3 bis quai Chauveau, CP 220, F-69336 Lyon, France

Corresponding author : cecile.miege@cemagref.fr

By means of a database including information from 117 international scientific papers, we present quantitative conclusions on the concentrations, frequencies of detection and removals of pharmaceutical products in wastewater treatment plants.

Abstract: We created a database in order to quantitatively assess the occurrence and removal efficiency of pharmaceuticals and personal care products (PPCPs) in wastewater treatment plants (WWTPs). From 117 scientific publications, we compiled 6641 data covering 184 PPCPs. Data included the concentrations of PPCPs in WWTP influents and effluents, their removal efficiency and their loads to the aquatic environment. The first outputs of our database allowed to identify the most investigated PPCPs in WWTPs and the most persistent ones, and to obtain reliable and quantitative values on their concentrations, frequency of detection and removal efficiency in WWTPs. We were also able to compare various processes and pointed out activated sludge with nitrogen treatment and membrane bioreactor as the most efficient ones.

Keywords: database; pharmaceuticals; personal care products; removal efficiency; wastewater treatment plants

INTRODUCTION

The concern for pharmaceuticals and personal care products (PPCPs) as toxic substances in the environment and the need to assess their environmental risk have greatly increased since the early nineties. Several reviews dealing with the exposition and effect of pharmaceuticals have been published recently (Halling-Sorensen *et al.*, 1998; Daughton and Ternes, 1999; Jorgensen and Halling-Sorensen 2000; Kümmerer, 2001; Ternes *et al.*, 2001; Heberer, 2002; Petrovic *et al.*, 2003; Larsen *et al.*, 2004; Janex-Habibi *et al.*, 2004; Jones *et al.*, 2004; Kuster *et al.*, 2004; Zwiener and Frimmel 2004; Garric and Ferrari, 2005; Hernando *et al.*, 2005; Fent *et al.*, 2006; Zuccato *et al.*, 2006). These reviews allow to identify more than one hundred pharmaceuticals and personal care

products from various prescription classes measured in WWTPs in several European countries, Brazil and North America. These PPCPs include analgesics and anti-inflammatory drugs, antibiotics and bacteriostatics, antiepileptics, betablockers, blood lipid regulators, contrast media, cytostatics, hormones (including oral contraceptives), antidepressants and anxiolytics, musk fragrances, disinfectants and antiseptics. These reviews outline the exposure routes to the aquatic and soils environment for different classes of drugs (Halling-Sorensen *et al.*, 1998; Jorgensen and Halling-Sorensen 2000; Kümmerer, 2001; Heberer, 2002), the environmental risk assessment strategy (Daughton and Ternes, 1999; Jones *et al.*, 2004; Garric and Ferrari, 2005; Hernando *et al.*, 2005; Fent *et al.*, 2006; Zuccato *et al.*, 2006). Some authors listed the annual quantities of PPCPs prescribed for different countries (Halling-Sorensen, 1998; Jorgensen and Halling-Sorensen 2000; Fent *et al.*, 2006). Two papers summarised the modes of action of PPCPs in humans and mammals (Fent *et al.*, 2006) and their metabolization in humans (Richardson and Bowron 1985). A few reviews deal with their effect and concentration in aquatic vertebrates and invertebrates (Halling-Sorensen, 1998; Daughton and Ternes, 1999; Jones *et al.*, 2004; Fent *et al.*, 2006). The analytical protocols to identify and quantify PPCPs in environmental matrices have also been scrutinized (Ternes *et al.*, 2001; Petrovic *et al.*, 2003; Kuster *et al.*, 2004; Zwiener and Frimmel 2004). Several papers present ranges of PPCPs concentrations in various compartments of the aquatic environment and in wastewaters (Halling-Sorensen, 1998; Daughton and Ternes, 1999; Kümmerer, 2001; Heberer, 2002; Garric and Ferrari, 2005; Fent *et al.*, 2006). Finally, a few papers present and compare the various processes used in WWTPs to eliminate PPCPs (Janex-Habibi *et al.*, 2004; Larsen *et al.*, 2004). Larsen *et al.* (2004) presented the source separation approach, which consists of pre-treatment of highly contaminated sources such as urines or wastewaters from hospitals.

However, we noted that the reviews dealing with the occurrence of PPCPs in wastewaters and their removal efficiency could not reach quantitative conclusions as they did not use a database to collect and process data from the literature.

Our objective in this study was to obtain reliable and quantitative information on PPCPs concentrations and removal efficiency and to study if existing data extracted from the literature permitted to establish trends on PPCPs removal efficiency for some processes or operating parameters.

We considered PPCPs used for human treatments and included antiseptics, hormones and personal care products. For the most studied PPCPs, we were able to compute mean and median liquid influent and effluent concentrations, mean removal efficiency, and we calculated minimum and

maximum values, and relative standard deviations. We also studied the influence of the type and the operating conditions of WWTPs in order to explain and to predict the fate of these contaminants in WWTPs.

DESCRIPTION OF THE DATABASE

We built our database from the compilation of 115 international research papers and 2 French research reports covering a period from January 1997 to June 2006 for international studies and from 1997 to February 2007 for French studies. These 117 scientific publications are reported in annex 1. We considered all pharmaceuticals used for human treatment and included hormones, antiseptics and personal care products (musk fragrances, sun-screen agents and insect repellents). The total number of molecules covered in the database reaches 184.

We recorded 6641 data from the literature including concentrations in influents (1602 data), concentrations in effluents (3120 data), loads of compounds (kg/d) to be treated in influents (115 data), loads released in the environment by effluents (186 data) and removal efficiency (1618 data) for the dissolved aqueous compartment of WWTPs. In this paper the removal of PPCPs in the dissolved phase is referred to as R.

In our database, values of R obtained with activated sludge processes (ASP) are well documented, with 742 data for the high sludge retention time configuration for nitrogen removal, 129 data for the low sludge retention time configuration for carbon removal, 185 for ASP with phosphorus treatment (and also nitrogen treatment for some of these 185 WWTPs). We also recorded R for other types of processes: membrane bioreactors with nitrogen treatment (63 data), pre-treatment and primary sedimentation tanks (49 data), fixed biomass systems (immersed biofilters, biodiscs and trickling filters, 18 data) and waste stabilization ponds (14 data).

To reach quantitative conclusions, we only considered concentrations and R in the dissolved phase of WWTPs as too few data are available for sludges and suspended solids. Only data obtained from 24h flow proportional composite sample were compiled, as it is the only way to obtain a sample representative of the wastewater that enter the treatment plants. When available, we favoured individual values of concentration or R. Nonetheless, we decided to use also mean values when the number of individual values was mentioned in the original paper so we could weight these mean values.

When it was available, we recorded detailed information on the WWTPs: design capacity (mean flow rate in m³/d and population equivalent); nature of influent (municipal, dry or wet weather influent, industrial, hospital); type of treatment (primary, secondary and tertiary stages); temperature and pH of the mixed liquor in the biological reactor; volume of the reactor; hydraulic and sludge retention times; physico-chemical characteristics of wastewaters (e.g., chemical oxygen demand and suspended solid concentration).

The sampling and analytical procedures were also documented in detail if available: period of the year (month or season, year), sampling type (grab, time or flow proportional), nature of the sample (raw sewage, pre-treatment effluent, primary, secondary or tertiary effluents), water fraction analysed (dissolved, particular, raw or total), description of the analytical method (extraction and purification steps, chromatographic analysis, use of internal standards), and description of the performances of the analytical method (recovery, relative standard deviation, limits of detection and quantification). But this information is rarely described in a comprehensive manner in papers dealing with pharmaceuticals occurrence in WWTP. Therefore, at this stage, it cannot be a selection criteria since it would have led us to suppress most of the available data from our analysis. This aspect will be the subject to a following publication dealing with the difficulty to assess the reliability of data in scientific papers on PPCPs in WWTPs.

RESULTS AND DISCUSSION

The PPCPs the most investigated in WWTPs

The molecules and the therapeutic classes the most investigated in WWTPs are reported in Table 1. The frequency of citation for each molecule was calculated as the ratio of the number of data recorded in the database for a given molecule over the total number of data for all studied molecules. We then compiled this information for each therapeutic class for the 80% most frequently cited molecules. The results show that the therapeutic classes the most cited in our database are hormones (30%, 7 molecules), analgesics and antiinflammatories (20%, 5 molecules) and antibiotics (9%, 7 molecules). Estrone and 17 β -estradiol are the most investigated molecules (553 and 543 data respectively, 8%). The lipid regulators, anti-epileptics, metabolites, betablockers, personal care products and contrast products cited in Table 1 have citation frequencies between 1 and 5%. For all other molecules, the frequency of citation is below 1%.

Thus, 33 molecules represent 80% of the recorded data. They have been investigated because they are highly prescribed and continuously discharged in the environment, and could be potentially toxic. For the other PPCPs (151 molecules), more limited information is available: e.g., citation frequency of only 0.6% for paracetamol and 0.3% for aspirin, bisoprolol and sotalol.

Concentrations of PPCPs in the dissolved phase of WWTP influents and effluents

The collected data covered influent and effluent concentrations for ASP combined with a pre-treatment, which could be associated, depending on the WWTP, with a primary sedimentation tank, a treatment of nitrogen and / or phosphorus, or a tertiary treatment. For all studied molecule, we calculated the mean, median, relative standard deviation (RSD), minimum and maximum concentrations of PPCPs in influent and effluent of WWTPs. For this calculation, we did not use values from pilot or batch experiments. The results are presented in Table 2 (in alphabetic order of molecule by therapeutic class). We only reported the results for the molecules for which a minimum of 3 concentration data were recorded for influent or for effluent. This represents a total of 43 molecules for influent concentrations and 43 molecules for effluent concentrations.

Generally, the frequency of quantification in influent and effluent is above 90% for a majority of molecules. Mean dissolved concentrations in the influent range from 4 ng/L for 17 α -ethinylestradiol (detected in 91% of the influent samples) to 212 μ g/L for salicylic acid (detected in 100 % of the influent samples). Salicylic acid may be a metabolite of acetylsalicylic acid, but there are several other possible sources of salicylic acid. The lowest influent concentrations quantified (ng/L level) are found for the hormones and the highest measured concentration (above 292 μ g/L) are recorded for some analgesic-antiinflammatory (naproxen and paracetamol) and a metabolite (salicylic acid). These influent concentrations depend mainly on the degree of prescription and human metabolization.

Mean dissolved concentrations in the effluent range from 0.8 ng/L for 17 α -estradiol (detected in 64% of the effluent samples) to 5.7 μ g/L for iopromide (detected in 57% of the effluent samples). As for the influent, we observe that the lowest quantified concentrations are found for hormones (around 0.1 ng/L) and the highest ones for analgesic-antiinflammatory (25 and 34 μ g/L for ibuprofen and naxopren, respectively).

RSD are between 10% and 150%. Some higher RSD (up to 365%) are found for 2 antiinflammatories (naproxen in influents and effluents, ibuprofen in effluents), 3 hormones (17 α ethinylestradiol in influents, 17 β estradiol and estriol in effluents) and 1 lipid regulator

(bezafibrate in effluents). These ranges of RSD values are mainly resulting from the large number and variety of WWTPs considered in these papers.

Removal of PPCPs in the dissolved aqueous phase of WWTPs

In the literature, the removal efficiency is generally computed as the percentage of reduction between the dissolved aqueous phase concentration of the contaminant in the influent and the dissolved aqueous phase concentration of the contaminant in the effluent. Except for a few recent studies, PPCPs concentrations in sludge or suspended solid are generally not considered nor measured, probably because of the difficulty to sample and to analyse such complex matrices. Only 15 publications, over the 117 publications studied, reported PPCPs concentrations in sludges and 1 in suspended solid. None of the 117 papers reported removal obtained taking into account both liquid and solid (sludges and suspended solids) compartments of WWTPs.

In order to compute statistics on R in the dissolved aqueous phase for the different molecules studied, we used results on R from our database with the following conditions: for measured and also calculated R from influent and effluent concentrations (if measured in the same WWTP); for full scale WWTP and pilots WWTP, but not for batch experiments; excluding negative values of R.

Removal for ASP for the studied molecules

We calculated mean R and RSD for WWTPs with ASP in order to evaluate the persistence of the studied PPCPs.

The collected data of R concerned ASP combined with a pre-treatment stage, which could be associated, depending on the WWTP, with a primary sedimentation tank and/or a treatment of phosphorus. Two types of ASP were considered: the ones that perform carbon removal (sludge age < 10 d), and the others that perform nitrogen removal (sludge age > 10d).

Mean values of R could be calculated for 50 molecules and the data set was equal to or above 3 for 32 molecules (Figure 1). Considering molecules with a minimum data set of 3, we could point out triclosan, norfloxacin, 17 β -estradiol and estriol as highly removed contaminants (R > 80%), whereas atenolol, carbamazepine, metoprolol, trimetoprim, mefenamic acid and clofibric acid have low removal efficiency (R < 30%). The RSD are quite variable, ranging from 22 to 143% (mean RSD=43%, median RSD=39%, n=32) for the different molecules (for those with a data set higher \geq 3). This variability could be mainly attributed to the variety of WWTPs from various countries considered. Nonetheless, the available database, coupled with a thorough data screening procedure,

succeeded to establish a relatively robust data set on R (dissolved fraction) for activated sludge treatment for these 32 molecules.

The main mechanisms involved in removal efficiency of PPCPs are biodegradation (e.g., oxidation, hydrolysis, demethylation, cleavage of glucuronide conjugates), sorption on sludge or particulate matter (by hydrophobic or electrostatic interactions), filtration and chemical oxidation. Loss by volatilization can be considered as negligible for PPCPs except for musk fragrances, which are slightly volatile (Larsen *et al.*, 2004).

Influence of the type of process on R values

According to our results, the type of WWTP process significantly influences R of PPCPs.

We computed mean R value for each molecule for the various studied processes (y axis) and plotted them against mean R value calculated for the same molecules for the ASP with nitrogen removal (x axis) (Figure 2). Indeed, we decided to use the ASP with nitrogen removal as a reference in our comparison, as it is nowadays the most common process over Europe since the discharge objectives stated by the European Commission (European Directive 91/271/EEC (1991)) with for instance about 75% of the current French WWTPs.

Primary treatment sedimentation tank provide R in the range 0-40% for the molecules tested (Figure 2A), whereas, R with biological treatment are mainly in the range 50-90% (Figure 2B). For most molecules, activated sludge with nitrogen removal (low loaded ASP) is more efficient than activated sludge without nitrogen removal (highly loaded ASP) (Figure 2B). Considering Figure 2B, most of the R values obtained with phosphorus activated sludge treatment are comparable to the ones recorded for activated sludge with nitrogen removal. However, for some molecules, R values appear to be higher or lower. This could be explained by the lack of specification on the type of process: indeed, the type of phosphorus removal (biological or chemical) is never specified in the original papers and the authors may also have omitted to mention an additional nitrogen treatment.

Removal for membrane bioreactor (MBR, which consists of ASP with very high sludge retention time and a filtration stage), fixed biomass reactor and waste stabilization ponds are compared to low loaded ASP in Figure 2C. Values of R for MBR are equivalent to R for low loaded ASP for some molecules (e.g., diclofenac, ibuprofen, sulfamethoxazole, carbamazepin, estrone) ; MBR is more efficient for three molecules (i.e., roxithromycin, tonalide and galaxolide). It is difficult to conclude on the R values with fixed growth biomass processes because of the too small number of data (only

6 molecules with both data on low loaded ASP and fixed growth biomass process). Fixed growth biomass process was found very efficient ($R > 92\%$) to remove estrone, 17α and β estradiol. It also allowed to remove tetracycline and sulfamethoxazole with R of 58 and 75% respectively. High values of R were obtained with waste stabilisation ponds: $R > 87\%$ for estrone, 17α and β estradiol, galaxolide and tonalide. This can be explained by the high hydraulic retention time (HRT) and sludge retention time (SRT) and also by possible photodegradation for this type of process. The two low R values obtained for fixed biomass reactor and waste stabilization pond in Figure 2C correspond to 17α -ethinylestradiol.

Influence of the influent concentration on R values

For each type of process, we also tested the influence of influent concentration on R of PPCPs. We examined only the data set (removal vs influent concentration) with more than 10 paired results. We were able to observe a tendency of higher values of R with higher influent concentration for 5 molecules over 9 with low loaded ASP: 3 hormones (17α ethinylestradiol, 17β estradiol, estriol), diclofenac and ketoprofen. For the 4 other molecules (estrone, ibuprofen, norfloxacin and mefenamic acid), no tendency were shown. We wonder if processes would be less efficient under a minimum influent concentration which would be interesting to determine and to compare with future regulations.

Influence of the operating conditions on R values

The hydraulic retention time (HRT) and the sludge retention time (SRT) are often used to explain the variation of PPCPs removal efficiency for WWTPs (Henze *et al.*, 1996, Clara *et al.*, 2005). Indeed, high retention times allow low rate reactions like biodegradation and sorption mechanisms to occur.

For several reasons, statistical analyse of the influence of SRT and HRT was difficult to perform using our database. Firstly, HRT and SRT were rarely mentioned in papers from our database on PPCPs in WWTPs. Secondly, most authors did not specify how they calculated HRT. Indeed, HRT could be calculated according to 2 different definitions, taking into account, or not, the flow of the recycling water. This difference of calculation may induce misinterpretations of the HRT influence on R. Thirdly, R can be influenced by various other factors, such as the temperature of the mixed liquor inside the biological reactor (T), the presence of inhibitors (antibiotics or metals), the concentration of the PPCP of interest in the influent, the pH in the biological reactor, the total suspended solids, the concentration of dissolved oxygen, the agitation condition, the nature of the molecule and the type of process. Fourthly, it is not possible to perform principal component

analysis and to test the effect of all factors, because our data set for each molecule is not complete. Indeed, a meticulous description of the WWTP process together with all operating factors are far from being presented in all papers dealing with PPCPs in WWTPs. And lastly, when testing one parameter influencing removal, it is necessary that the other ones do not vary, which is not necessarily verified when compiling data from various authors.

To conclude, more specific in situ study with pilot seems to be necessary to rigorously put in light the effect of T, HRT and SRT as it was done for example by Clara *et al.* (2005).

CONCLUSION AND PERSPECTIVES

Using our database, we were able to identify the most investigated PPCPs in WWTPs and the most persistent ones in the dissolved phase. We also computed reliable and quantitative values on concentrations, frequency of detection and removals for about 50 molecules. We could compare various WWTP processes for a limited number of molecules and pointed out activated sludge with nitrogen treatment and membrane bioreactor as the most efficient ones.

By further statistical tests compiling data from our database, it was difficult to conclude on the influence of operating conditions, such as T, SRT, HRT, on PPCPs removal. Indeed, a limit of such a database is that it is not possible to perform PCA since the dataset is rarely complete (i.e. lack of information on process or operating conditions for each molecule removal data). Furthermore, it is not possible to test each operating condition independently as in real conditions, they could vary together.

These results do not take into account the full removal of PPCP in WWTPs as only the dissolved concentrations are usually measured and reported in the literature. This probably does not change results dramatically for hydrophilic molecules, but it cannot be overlooked for more hydrophobic compounds, such as hormones for instance.

ACKNOWLEDGEMENTS

This work has been supported by the French National Research Agency (ANR, AMPERES project), the European Commission projects NORMAN and KNAPPE and the French Water Agency Rhône Méditerranée et Corse.

REFERENCES

- Clara, M., Strenn, B., Gans, O., Martinez, E., Kreuzinger, N., Kroiss, H., 2005. Removal of selected pharmaceuticals, fragrances and endocrine disrupting compounds in a membrane bioreactor and conventional wastewater treatment plants. *Water Research* 39, 4797-4807.
- Daughton, C.G., Ternes, T.A., 1999. Pharmaceuticals and personal care products in the environment: Agents of subtle change? *Environmental Health Perspectives* 107 Supplement 6, 907-938.
- European directive 91/271/EEC (1991), Urban wastewater treatment.
- Fent, K., Weston, A.A., Caminada, D., 2006. Ecotoxicology of human pharmaceuticals. *Aquat. Toxicol.* 76, 122-159.
- Garric, J., Ferrari, B., 2005. Pharmaceuticals in aquatic ecosystems. Levels of exposure and biological effects : a review. *Rev. Sci. Eau* 18/3.
- Halling-Sorensen, B., Nielsen, S.N., Lanzky, P.F., Ingerslev, F., Lutzhoft, H.C.H., Jorgensen, S.E., 1998. Occurrence, fate and effects of pharmaceutical substances in the environment - A review. *Chemosphere* 36, 357-394.
- Heberer, T., 2002. Occurrence, fate, and removal of pharmaceutical residues in the aquatic environment: A review of recent research data. *Toxicology Letters* 131, 5-17.
- Henze, M., Harremoës, P., la Cour Jansen, J. and Arvin, A., 1996. *Wastewater Treatment. Biological and Chemical processes.* Springer-Verlag 383 p.
- Hernando, M.D., Fernandez-Alba, A.R., Tauler, R., Barcelo, D., 2005. Toxicity assays applied to wastewater treatment. *Talanta* 65, 358-366.
- Janex-Habibi, M.L., Bruchet, A., Ternes, T.A., 2004. Effet des traitements d'eau potable et d'épuration des eaux usées sur les résidus médicamenteux. Résultats du projet Poseidon. *TSM* 11.
- Jones, A.H., Voulvoulis, N., Lester, J.N., 2004. Potential ecological and human health risks associated with the presence of pharmaceutically active compounds in the aquatic environment. *Critical Reviews in Toxicology* 34, 335-350.
- Jorgensen, S.E., Halling-Sorensen, B., 2000. Drugs in the environment. *CHEMOSPHERE* 40, 691-699.
- Kummerer, K., 2001. Drugs in the environment: Emission of drugs, diagnostic aids and disinfectants into wastewater by hospitals in relation to other sources - A review. *Chemosphere* 45, 957-969.
- Kuster, M., Jose Lopez de Alda, M., Barcelo, D., 2004. Analysis and distribution of estrogens and progestogens in sewage sludge, soils and sediments. *TrAC Trends in Analytical Chemistry* 23, 790-798.
- Larsen, T.A., Lienert, J., Joss, A., Siegrist, H., 2004. How to avoid pharmaceuticals in the aquatic environment. *Journal of Biotechnology* 113, 295-304.
- Petrovic, M., Gonzalez, S., Barcelo, D., 2003. Analysis and removal of emerging contaminants in wastewater and drinking water. *Trac-Trends Anal. Chem.* 22, 685-696.
- Ternes, T.A., Bonerz, M., Schmidt, T., 2001. Determination of neutral pharmaceuticals in wastewater and rivers by liquid chromatography-electrospray tandem mass spectrometry. *Journal of Chromatography A* 938 (1-2), 175-185.
- Zuccato, E., Castiglioni, S., Fanelli, R., Reitano, G., Bagnati, R., Chiabrando, C., Pomati, F., Rossetti, C., Calamari, D. 2006. Pharmaceuticals in the environment in Italy: Causes, occurrence, effects and control. *Environmental Science and Pollution Research* 13 (1), 15-21
- Zwiener, C., Frimmel, F.H., 2004. LC-MS analysis in the aquatic environment and in water treatment technology - a critical review - Part II: Applications for emerging contaminants and related pollutants, microorganisms and humic acids. *Analytical and Bioanalytical Chemistry* 378, 862-874.

ANNEX 1 : List of publications used in the database

- Adams, C., Wang, Y., Loftin, K., Meyer, M., 2002. Removal of antibiotics from surface and distilled water in conventional water treatment processes. *Journal of Environmental Engineering-Asce* 128, 253-260.
- Andersen, H., Siegrist, H., Halling-Sorensen, B., Ternes, T.A., 2003. Fate of estrogens in a municipal sewage treatment plant. *Environmental Science & Technology* 37, 4021-4026.
- Andreozzi, R., Campanella, L., Fraysse, B., Garric, J., Gonnella, A., Lo Giudice, R., Marotta, R., Pinto, G., Pollio, A., 2004. Effects of advanced oxidation processes (AOPs) on the toxicity of a mixture of pharmaceuticals. *Water Science and Technology* 50, 23-28.
- Andreozzi, R., Canterino, M., Lo Giudice, R., Marotta, R., Pinto, G., Pollio, A., 2006. Lincomycin solar photodegradation, algal toxicity and removal from wastewaters by means of ozonation. *Water Research* 40, 630-638.
- Andreozzi, R., Canterino, M., Marotta, R., Paxeus, N., 2005. Antibiotic removal from wastewaters: The ozonation of amoxicillin. *J. Hazard. Mater.* 122, 243-250.
- Andreozzi, R., Caprio, V., Ciniglia, C., De Champdore, M., Lo Giudice, R., Marotta, R., Zuccato, E., 2004. Antibiotics in the environment: Occurrence in Italian STPs, fate, and preliminary assessment on algal toxicity of amoxicillin. *Environmental Science & Technology* 38, 6832-6838.
- Andreozzi, R., Caprio, V., Marotta, R., Radovnikovic, A., 2003. Ozonation and H₂O₂/UV treatment of clofibrac acid in water: a kinetic investigation. *J. Hazard. Mater.* 103, 233-246.
- Andreozzi, R., Caprio, V., Marotta, R., Vogna, D., 2003. Paracetamol oxidation from aqueous solutions by means of ozonation and H₂O₂/UV system. *Water Research* 37, 993-1004.
- Andreozzi, R., Raffaele, M., Nicklas, P., 2003. Pharmaceuticals in STP effluents and their solar photodegradation in aquatic environment. *Chemosphere* 50, 1319-1330.
- Ashton, D., Hilton, M., Thomas, K.V., 2004. Investigating the environmental transport of human pharmaceuticals to streams in the United Kingdom. *Science of the Total Environment* 333, 167-184.
- Baronti, C., Curini, R., D'Ascenzo, G., Di Corcia, A., Gentili, A., Samperi, R., 2000. Monitoring natural and synthetic estrogens at activated sludge sewage treatment plants and in a receiving river water. *Environmental Science & Technology* 34, 5059-5066.
- Batt, A.L., Kim, S., Aga, D.S., 2006. Enhanced biodegradation of loperamide and trimethoprim in nitrifying activated sludge. *Environmental Science and Technology* 40(23), 7367-7373
- Belfroid, A.C., Van der Horst, A., Vethaak, A.D., Schafer, A.J., Rijs, G.B.J., Wegener, J., Cofino, W.P., 1999. Analysis and occurrence of estrogenic hormones and their glucuronides in surface water and waste water in The Netherlands. *Science of the Total Environment* 225, 101-108.
- Bendz, D., Paxeus, N.A., Ginn, T.R., Loge, F.J., 2005. Occurrence and fate of pharmaceutically active compounds in the environment, a case study: Hoje River in Sweden. *J. Hazard. Mater.* 122, 195-204.
- Boyd, G.R., Reemtsma, H., Grimm, D.A., Mitra, S., 2003. Pharmaceuticals and personal care products (PPCPs) in surface and treated waters of Louisiana, USA and Ontario, Canada. *The Science of The Total Environment* 311, 135-149.
- Braga, O., Smythe, G.A., Schafer, A.I., Feitz, A.J., 2005. Fate of steroid estrogens in Australian inland and coastal wastewater treatment plants. *Environmental Science & Technology* 39, 3351-3358.
- Braga, O., Smythe, G.A., Schafer, A.I., Feltz, A.J., 2005. Steroid estrogens in primary and tertiary wastewater treatment plants. *Water Science and Technology* 52, 273-278.
- Brown, K.D. (2004) Pharmaceutically active compounds in residential and hospital effluents, municipal wastewater, and the Rio Grande in Albuquerque, New Mexico., University of New Mexico.
- Bruchet, A., Castillo, L., Esperanza, M., Janex-Habibi, M.L., Herry, G., Huyard, A., Pasanau, J., 2006. Présence et devenir des perturbateurs endocriniens dans les stations de traitement des eaux résiduaires urbaines.
- Buerge, I.J., Buser, H.R., Poiger, T., Müller, M.D., 2006. Occurrence and fate of the cytostatic drugs cyclophosphamide and ifosfamide in wastewater and surface waters. *Environ. Sci. Technol.* 40, 7242-7250.
- Buser, H. R., Poiger, T. and Muller, M. D., 1998. Occurrence and fate of the pharmaceutical drug diclofenac in surface waters: Rapid photodegradation in a lake. *Environmental Science & Technology* 32(22): 3449-3456.
- Buser, H.R., Poiger, T., Muller, M.D., 1999. Occurrence and environmental behavior of the chiral pharmaceutical drug ibuprofen in surface waters and in wastewater. *Environmental Science & Technology* 33, 2529-2535.

- Carballa, M., Omil, F., Lema, J.M., Llompart, M., Garcia-Jares, C., Rodriguez, I., Gomez, M., Ternes, T., 2004. Behavior of pharmaceuticals, cosmetics and hormones in a sewage treatment plant. *Water Research* 38, 2918-2926.
- Carballa, M., Omil, F., Lema, J.M., Llompart, M., Garcia, C., Rodriguez, I., Gomez, M., Ternes, T., 2005. Behavior of pharmaceuticals and personal care products in a sewage treatment plant of northwest Spain. *Water Science and Technology* 52, 29-35.
- Cargouet, M., Perdiz, D., Mouatassim-Souali, A., Tamisier-Karolak, S., Levi, Y., 2004. Assessment of river contamination by estrogenic compounds in Paris area (France). *Science of the Total Environment* 324, 55-66.
- Castiglioni, S., Bagnati, R., Fanelli, R., Pomati, F., Calamari, D., Zuccato, E., 2006. Removal of pharmaceuticals in sewage treatment plants in Italy. *Environmental Science & Technology* 40, 357-363.
- Clara, M., Kreuzinger, N., Strenn, B., Gans, O., Kroiss, H., 2005. The solids retention time - a suitable design parameter to evaluate the capacity of wastewater treatment plants to remove micropollutants. *Water Research* 39, 97-106.
- Clara, M., Strenn, B., Ausserleitner, M., Kreuzinger, N., 2004. Comparison of the behaviour of selected micropollutants in a membrane bioreactor and a conventional wastewater treatment plant. *Water Science and Technology* 50, 29-36.
- Clara, M., Strenn, B., Gans, O., Martinez, E., Kreuzinger, N., Kroiss, H., 2005. Removal of selected pharmaceuticals, fragrances and endocrine disrupting compounds in a membrane bioreactor and conventional wastewater treatment plants. *Water Research* 39, 4797-4807.
- Clara, M., Strenn, B., Kreuzinger, N., 2004. Carbamazepine as a possible anthropogenic marker in the aquatic environment: investigations on the behaviour of Carbamazepine in wastewater treatment and during groundwater infiltration. *Water Research* 38, 947-954.
- Dagnac, T., Bristeau, S., Coton, C., Leroy, C., Fleury, N., Jeannot, R., 2005. Analyse de polluants organiques et organométalliques dans l'environnement.
- Desbrow, C., Routledge, E.J., Brighty, G.C., Sumpter, J.P., Waldock, M., 1998. Identification of estrogenic chemicals in STW effluent. 1. Chemical fractionation and in vitro biological screening. *Environmental Science & Technology* 32, 1549-1558.
- Drewes, J.E., Heberer, T., Reddersen, K., 2002. Fate of pharmaceuticals during indirect potable reuse. *Water Science and Technology* 46, 73-80.
- Drewes, J.E., Hemming, J., Ladenburger, S., Schauer, J., Sonzogni, W., 2005. Endocrine disrupting activity changes in water reclamation systems. *Water environment federation*.
- Drewes, J.E., Hemming, J., Ladenburger, S.J., Schauer, J., Sonzogni, W., 2005. An assessment of endocrine disrupting activity changes during wastewater treatment through the use of bioassays and chemical measurements. *Wat. Environ. Res.* 77, 12-23.
- Esperanza, M., Suidan, M.T., Marfil-Vega, R., Gonzalez, C., Sorial, G.A., McCauley, P., Brenner, R., 2007. Fate of sex hormones in two pilot-scale municipal wastewater treatment plants: Conventional treatment. *Chemosphere* 66, 1535-1544.
- Esperanza, M., Suidan, M.T., Nishimura, F., Wang, Z.M., Sorial, G.A., 2004. Determination of sex hormones and nonylphenol ethoxylates in the aqueous matrixes of two pilot-scale municipal wastewater treatment plants. *Environmental Science & Technology* 38, 3028-3035.
- Esperanza M., Suidan M. T., Vega R. M., Gonzalez C., Sorial G. A., Paul McCauley, P., Brenner R., 2007. Fate of sex hormones in two pilot-scale municipal wastewater treatment plants: Conventional treatment. *Chemosphere*. 66: 1535-1544.
- Farre, M., Ferrer, I., Ginebreda, A., Figueras, M., Olivella, L., Tirapu, L., Vilanova, M., Barcelo, D., 2001. Determination of drugs in surface water and wastewater samples by liquid chromatography-mass spectrometry: methods and preliminary results including toxicity studies with *Vibrio fischeri*. *Journal of Chromatography A* 938, 187-197.
- Gobel, A., Thomsen, A., McArdell, C.S., Joss, A., Giger, W., 2005. Occurrence and sorption behavior of sulfonamides, macrolides, and trimethoprim in activated sludge treatment. *Environmental Science & Technology* 39, 3981-3989.
- Golet, E.M., Alder, A.C., Hartmann, A., Temes, T.A., Giger, W., 2001. Trace determination of fluoroquinolone antibacterial agents in urban wastewater by solid-phase extraction and liquid chromatography with fluorescence detection. *Analytical Chemistry* 73, 3632-3638.
- Golet, E.M., Xifra, I., Siegrist, H., Alder, A.C., Giger, W., 2003. Environmental exposure assessment of fluoroquinolone antibacterial agents from sewage to soil. *Environmental Science & Technology* 37, 3243-3249.

- Gross, B., Montgomery-Brown, J., Naumann, A., Reinhard, M., 2004. Occurrence and fate of pharmaceuticals and alkylphenol ethoxylate metabolites in an effluent-dominated river and wetland. *Environmental Toxicology and Chemistry* 23, 2074-2083.
- Han, G.H., Hur, H.G., Kim, S.D., 2006. Ecotoxicological risk of pharmaceuticals from wastewater treatment plants in Korea: Occurrence and toxicity to *Daphnia magna*. *Environmental Toxicology and Chemistry* 25, 265-271.
- Hannich, C.B., Ries, T., Fahlenkamp, H., 2005. Occurrence and elimination of organic compounds in municipal wastewater treatment plants.
- Heberer, T., 2002. Tracking persistent pharmaceutical residues from municipal sewage to drinking water. *Journal of Hydrology* 266, 175-189.
- Heberer, T., Feldmann, D., Reddersen, K., Altmann, H.J., Zimmermann, T., 2001. Removal of pharmaceutical residues and other persistent organics from municipal sewage and surface waters applying membrane filtration. 18-29.
- Heidler, J. and Halden, R. U., 2007. Mass balance assessment of triclosan removal during conventional sewage treatment. *Chemosphere* 66(2): 362-369.
- Herry-Leroy, G., Raulet, C., Beausse, J., 2006. Study of new emerging pollutants in the environment : Endocrine disrupters - analysis of steroid hormones in waste water treatment plants using LC/MS-MS. *European journal of water quality* 37, 39-52.
- Hirsch, R., Ternes, T., Haberer, K., Kratz, K.-L., 1999. Occurrence of antibiotics in the aquatic environment. *Science of the Total Environment* 225, 109-118.
- Hua, J.M., An, P.L., Winter, J., Gallert, C., 2003. Elimination of COD, microorganisms and pharmaceuticals from sewage by trickling through sandy soil below leaking sewers. *Water Research* 37, 4395-4404.
- Huber, M.M., Canonica, S., Park, G.Y., Von Gunten, U., 2003. Oxidation of pharmaceuticals during ozonation and advanced oxidation processes. *Environmental Science & Technology* 37, 1016-1024.
- Huber, M.M., Gobel, A., Joss, A., Hermann, N., Löffler, D., McArdeell, C.S., Ried, A., Siegrist, H., Ternes, T.A., von Gunten, U., 2005. Oxidation of pharmaceuticals during ozonation of municipal wastewater effluents: A pilot study. *Environmental Science & Technology* 39, 4290-4299.
- Huber, M.M., Korhonen, S., Ternes, T.A., von Gunten, U., 2005. Oxidation of pharmaceuticals during water treatment with chlorine dioxide. *Water Research* 39, 3607-3617.
- Huggett, D.B., Khan, I.A., Foran, C.M., Schlenk, D., 2003. Determination of beta-adrenergic receptor blocking pharmaceuticals in united states wastewater effluent. *Environmental Pollution* 121, 199-205.
- Johnson, A.C., Aerni, H.R., Gerritsen, A., Gibert, M., Giger, W., Hylland, K., Jurgens, M., Nakari, T., Pickering, A., Suter, M.J.F., Svenson, A., Wettstein, F.E., 2005. Comparing steroid estrogen, and nonylphenol content across a range of European sewage plants with different treatment and management practices. *Water Research* 39, 47-58.
- Johnson, A.C., Belfroid, A., Di Corcia, A., 2000. Estimating steroid oestrogen inputs into activated sludge treatment works and observations on their removal from the effluent. *Science of the Total Environment* 256, 163-173.
- Joss, A., Andersen, H., Ternes, T., Richle, P.R., Siegrist, H., 2004. Removal of estrogens in municipal wastewater treatment under aerobic and anaerobic conditions: Consequences for plant optimization. *Environmental Science & Technology* 38, 3047-3055.
- Kanda, R., Griffin, P., James, H.A., Fothergill, J., 2003. Pharmaceutical and personal care products in sewage treatment works. *Journal of Environmental Monitoring* 5, 823-830.
- Karthikeyan, K.G., Meyer, M.T., 2006. Occurrence of antibiotics in wastewater treatment facilities in Wisconsin, USA. *Science of the Total Environment* 361 (1-3), 196-207.
- Khan, S.J., Ongerth, J.E., 2002. Estimation of pharmaceutical residues in primary and secondary sewage sludge based on quantities of use and fugacity modelling. *Water Science and Technology* 46, 105-113.
- Kimura, K., Amy, G., Drewes, J.E., Heberer, T., Kim, T.U., Watanabe, Y., 2003. Rejection of organic micropollutants (disinfection by-products, endocrine disrupting compounds, and pharmaceutically active compounds) by NF/RO membranes. *Journal of Membrane Science* 227, 113-121.
- Kimura, K., Hara, H., Watanabe, Y., 2005. Removal of pharmaceutical compounds by submerged membrane bioreactors (MBRs). *Desalination* 178, 135-140.
- Kimura, K., Toshima, S., Amy, G., Watanabe, Y., 2004. Rejection of neutral endocrine disrupting compounds (EDCs) and pharmaceutical active compounds (PhACs) by RO membranes. *Journal of Membrane Science* 245, 71-78.
- Komori, K., Tanaka, H., Okayasu, Y., Yasojima, M., Sato, C., 2004. Analysis and occurrence of estrogen in wastewater in Japan. *Water Science and Technology* 50, 93-100.

Koutsouba, V., Heberer, T., Fuhrmann, B., Schmidt-Baumler, K., Tsipi, D., Hiskia, A., 2003. Determination of polar pharmaceuticals in sewage water of Greece by gas chromatography-mass spectrometry. *Chemosphere* 51, 69-75.

Kuch, H.M., Ballschmiter, K., 2000. Determination of endogenous and exogenous estrogens in effluents from sewage treatment plants at the ng/L-level. *Fresenius Journal of Analytical Chemistry* 366, 392-395.

Kummerer, K., StegerHartmann, T., Meyer, M., 1997. Biodegradability of the anti-tumour agent ifosfamide and its occurrence in hospital effluents and communal sewage. *Water Research* 31, 2705-2710.

Labadie, P., Budzinski, H., 2005. Determination of steroidal hormone profiles along the Jalle d'Eysines River (near Bordeaux, France). *Environmental Science & Technology* 39, 5113-5120.

Labadie, P., Budzinski, H., 2005. Development of an analytical procedure for determination of selected estrogens and progestagens in water samples. *Anal. Bioanal. Chem.* 381, 1199-1205.

Layton, A.C., Gregory, B.W., Seward, J.R., Schultz, T.W., Sayler, G.S., 2000. Mineralization of steroidal hormones by biosolids in wastewater treatment systems in Tennessee USA. *Environmental Science & Technology* 34, 3925-3931.

Lindqvist, N., Tuhkanen, T., Kronberg, L., 2005. Occurrence of acidic pharmaceuticals in raw and treated sewages and in receiving waters. *Water Research* 39, 2219-2228.

Lishman, L., Smyth, S.A., Sarafin, K., Kleywegt, S., Toito, J., Peart, T., Lee, B., Servos, M., Beland, M., Seto, P., 2006. Occurrence and reductions of pharmaceuticals and personal care products and estrogens by municipal wastewater treatment plants in Ontario, Canada. *Science of the Total Environment* 367, 544.

Loraine, G.A., Pettigrove, M.E., 2006. Seasonal variations in concentrations of pharmaceuticals and personal care products in drinking water and reclaimed wastewater in Southern California. *Environmental Science & Technology* 40, 687-695.

Matamoros, V., Garcia, J., Bayona, J.M., 2005. Behavior of selected pharmaceuticals in subsurface flow constructed wetlands: A pilot-scale study. *Environmental Science & Technology* 39, 5449-5454.

McArdell, C.S., Molnar, E., Suter, M.J.F., Giger, W., 2003. Occurrence and fate of macrolide antibiotics in wastewater treatment plants and in the Glatt Valley Watershed, Switzerland. *Environmental Science & Technology* 37, 5479-5486.

Metcalf, C.D., Koenig, B.G., Bennie, D.T., Servos, M., Ternes, T.A., Hirsch, R., 2003. Occurrence of neutral and acidic drugs in the effluents of canadian sewage treatment plants. *Environmental Toxicology and Chemistry* 22, 2872-2880.

Metcalf, C.D., Miao, X.S., Koenig, B.G., Struger, J., 2003. Distribution of acidic and neutral drugs in surface waters near sewage treatment plants in the lower Great Lakes, Canada. *Environmental Toxicology and Chemistry* 22, 2881-2889.

Miao, X.S., Yang, J.J., Metcalfe, C.D., 2005. Carbamazepine and its metabolites in wastewater and in biosolids in a municipal wastewater treatment plant. *Environmental Science & Technology* 39, 7469-7475.

Miège, C., Favier, M., Brosse, C., Canler, J., Coquery, M., 2006. Occurrence of betablockers in effluents of wastewater treatment plants from the Lyon area (France) and risk assessment for the downstream rivers. *Talanta* 70, 739-744.

Mouatassim-Souali, A., Tamisier-Karolak, S., Perdiz, D., Cargouet, M., Levi, Y., 2003. Validation of a quantitative assay using GC/MS for trace determination of free and conjugated estrogens in environmental water samples. *J. Sep. Sci.* 26, 105-111.

Nasu, M., Goto, M., Kato, H., Oshima, Y., Tanaka, H., 2001. Study on endocrine disrupting chemicals in wastewater treatment plants. *Water Science and Technology* 43, 101-108.

Ollers, S., Singer, H.P., Fassler, P., Muller, S.R., 2001. Simultaneous quantification of neutral and acidic pharmaceuticals and pesticides at the low-ng/l level in surface and waste water. *Journal of Chromatography A* 911, 225-234.

Paffoni, C., Welte, B., Gousailles, M., Montiel, A., 2006. New molecules involved by the european directives : from wastewater to drinking water treatment plants. *European journal of water quality* 37, 21-38.

Paxeus, N., 2004. Removal of selected non-steroidal anti-inflammatory drugs (NSAIDs), gemfibrozil, carbamazepine, -blockers, trimethoprim and triclosan in conventional wastewater treatment plants in five EU countries and their discharge to the aquatic environment. *Water Science and Technology* 50, 253-260.

Petrovic, M., Sole, M., de Alda, M.J.L., Barcelo, D., 2002. Endocrine disruptors in sewage treatment plants, receiving river waters, and sediments: Integration of chemical analysis and biological effects on feral carp. *Environmental Toxicology and Chemistry* 21, 2146-2156.

Rabiet, M., Togola, A., Brissaud, F., Seidel, J.-L., Budzinski, H., Elbaz-poulichet, F., 2006. Consequences of treated water recycling as regards pharmaceuticals and drugs in surface and ground waters of a medium-sized mediterranean catchment. *Environmental Science & Technology* 40, 5282-5288.

Reinhard, M., Gross, B., Haderer, A., 2003. Emerging contaminants in tertiary treated wastewater. *Chimia* 57, 31-32.

Roberts, P. H. and Thomas, K. V., 2005. "The occurrence of selected pharmaceuticals in wastewater effluents and surface waters of the lower Tyne catchment." *Science of the Total Environment* 356: 143-153.

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

Santos, J.L., Aparicio, I., Alonso, E., Callejon, M., 2005. Simultaneous determination of pharmaceutically active compounds in wastewater samples by solid phase extraction and high-performance liquid chromatography with diode array and fluorescence detectors. *Analytica Chimica Acta* 550, 116-122.

Sedlak, D.L., Pinkston, K.E., 2001. Factors affecting the concentrations of pharmaceuticals released to the aquatic environment. *Water resources Update*, 56-64.

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., 2005. Distribution of estrogens, 17 beta-estradiol and estrone, in Canadian municipal wastewater treatment plants. *Science of the Total Environment* 336, 155-170.

Soulet, B., Tauxe, A., Tarradellas, J., 2002. Analysis of acidic drugs in Swiss wastewaters. *International Journal of Environmental Analytical Chemistry* 82, 659-667.

Strenn, B., Clara, M., Gans, O., Kreuzinger, N., 2004. Carbamazepine, diclofenac, ibuprofen and bezafibrate - investigations on the behaviour of selected pharmaceuticals during wastewater treatment. *Water Science and Technology* 50, 269-276.

Stumpf, M., Ternes, T.A., Wilken, R.-D., Silvana Vianna Rodrigues, Baumann, W., 1999. Polar drug residues in sewage and natural waters in the state of Rio de Janeiro, Brazil. *The Science of The Total Environment* 225, 135-141.

Suarez, S., Ramill, M., Omil, F., Lema, J.M., 2005. Removal of pharmaceutically active compounds in nitrifying-denitrifying plants. *Water Science and Technology* 52, 9-14.

Tauxe-Wuersch, A., De Alencastro, L.F., Grandjean, D., Tarradellas, J., 2005. Occurrence of several acidic drugs in sewage treatment plants in Switzerland and risk assessment. *Water Research* 39, 1761-1772.

Tauxe-Wuersch, A., de Alencastro, L.F., Grandjean, D., Tarradellas, J., 2006. Trace determination of tamoxifen and 5-fluorouracil in hospital and urban wastewaters. *International Journal of Environmental Analytical Chemistry* 86, 473-485.

Ternes, T.A., 1998. Occurrence of drugs in German sewage treatment plants and rivers. *Water Research* 32, 3245-3260.

Ternes, T.A., Bonerz, M., Schmidt, T., 2001. Determination of neutral pharmaceuticals in wastewater and rivers by liquid chromatography-electrospray tandem mass spectrometry. *Journal of Chromatography A* 938 (1-2), 175-185.

Ternes, T.A., Hirsch, R., 2000. Occurrence and behavior of X-ray contrast media in sewage facilities and the aquatic environment. *Environmental Science and Technology* 34, 2741-2748.

Ternes, T.A., Meisenheimer, M., McDowell, D., Sacher, F., Brauch, H.-J., Haist-Gulde, B., Preuss, G., Wilme, U., Zulei-Seibert, N., 2002. Removal of pharmaceuticals during drinking water treatment. *Environmental Science and Technology* 36, 3855-3863.

Ternes, T.A., Stuber, J., Herrmann, N., McDowell, D., Ried, A., Kampmann, M., Teiser, B., 2003. Ozonation: A tool for removal of pharmaceuticals, contrast media and musk fragrances from wastewater? *Water Research* 37, 1976-1982.

Ternes, T.A., Stumpf, M., Mueller, J., Haberer, K., Wilken, R.-D., Servos, M., 1999. Behavior and occurrence of estrogens in municipal sewage treatment plants - I. Investigations in Germany, Canada and Brazil. *Science of the Total Environment* 225, 81-90.

Ternes, T.A., Stumpf, M., Schuppert, B., Haberer, K., 1998. Simultaneous determination of antiseptics and acidic drugs in sewage and river water. *Vom Wasser* 90, 295-309.

Tixier, C., Singer, H.P., Oellers, S., Muller, S.R., 2003. Occurrence and fate of carbamazepine, clofibric acid, diclofenac, ibuprofen, ketoprofen, and naproxen in surface waters. *Environmental Science & Technology* 37, 1061-1068.

Urase, T., Kagawa, C., Kikuta, T., 2005. Factors affecting removal of pharmaceutical substances and estrogens in membrane separation bioreactors. *Desalination* 178, 107-113.

Vader, J. S., van Ginkel, C. G., Sperling, F., de Jong, J., de Boer, W., de Graaf, J. S., van der Most, M. and Stokman, P. G. W., 2000. Degradation of ethinyl estradiol by nitrifying activated sludge. *Chemosphere* 41(8): 1239-1243.

- Vieno, N.M., Tuhkanen, T., Kronberg, L., 2005. Seasonal variation in the occurrence of pharmaceuticals in effluents from a sewage treatment plant and in the recipient water. *Environmental Science & Technology* 39, 8220-8226.
- Weber, S., Gallenkemper, M., Melin, T., Dott, W., Hollender, J., 2004. Efficiency of nanofiltration for the elimination of steroids from water. *Water Science and Technology* 50, 9-14.
- Weigel, S., Berger, U., Jensen, E., Kallenborn, R., Thoresen, H., Huhnerfuss, H., 2004. Determination of selected pharmaceuticals and caffeine in sewage and seawater from Tromsø/Norway with emphasis on ibuprofen and its metabolites. *Chemosphere* 56, 583-592.
- Westerhoff, P., Yoon, Y., Snyder, S., Wert, E., 2005. Fate of endocrine-disruptor, pharmaceutical, and personal care product chemicals during simulated drinking water treatment processes. *Environmental Science & Technology* 39, 6649-6663.
- Yang, S., Carlson, K., 2004. Routine monitoring of antibiotics in water and wastewater with a radioimmunoassay technique. *Water Research* 38, 3155-3166.
- Yasojima, M., Nakada, N., Komori, K., Suzuki, Y., Tanaka, H., 2006. Occurrence of levofloxacin, clarithromycin and azithromycin in wastewater treatment plant in Japan. *Water Science and Technology* 53, 227-233.
- Zuehlke, S., Duennbier, U., Heberer, T., 2004. Determination of polar drug residues in sewage and surface water applying liquid chromatography-tandem mass spectrometry. *Analytical Chemistry* 76, 6548-6554.
- Zwiener, C., Glauner, T., Frimmel, F.H., 2000. Biodegradation of pharmaceutical residues investigated by SPE-GC/ITD-MS and on-line derivatization. *HRC-J. High Resolut. Chromatogr.* 23, 474-478.
- Zwiener, C., Seeger, S., Glauner, T., Frimmel, F.H., 2002. Metabolites from the biodegradation of pharmaceutical residues of ibuprofen in biofilm reactors and batch experiments. *Analytical and Bioanalytical Chemistry* 372, 569-575.

Table 1: The pharmaceuticals and personal care products the most investigated in wastewater treatment plants.

Therapeutic class	Molecules	Frequency (%)^a
Hormone	Estrone, 17 β -estradiol, 17 α -ethinylestradiol, Estriol, 17 α -estradiol, Testosterone, Progesterone	30
Analgesic-antiinflammatory	Ibuprofen, Diclofenac, Naproxen, Ketoprofen, Mefenamic acid	20
Antibiotic	Sulfamethoxazole, Trimetoprim, Ciprofloxacin, Roxithromycin, Norfloxacin, Clarithromycin, Erythromycin	8.7
Lipid regulator	Bezafibrate, Gemfibrozil	4.4
Anti-epileptic	Carbamazepin	4.0
Metabolite	Clofibric acid, Salicylic acid	3.9
Betablocker	Metoprolol, Propranolol, Atenolol	2.8
Personal care product	Galaxolide, Tonalide	2.7
Contrast product	Iopromide	1.1
Disinfectant	Triclosan	0.8
Vasodilator	Pentoxifyllin	0.7
Antidepressant	Diazepam	0.6
Total		80

^a: frequency of citation in our database (117 papers, 6641 data, 184 molecules)

Table 2: Mean, minimum and maximum concentrations of pharmaceuticals and personal care products in wastewater treatment plants with activated sludge processes (reported only for individual and mean value with a data set $n \geq 3$ for influent or effluent). / : no individual value reported

Therapeutic class	Name	Concentration in influent ($\mu\text{g/L}$)						Frequency of quantification in influent (%)	Concentration in effluent ($\mu\text{g/L}$)						Frequency of quantification in effluent (%)
		Mean	RSD (%)	Median	Min	Max	n		Mean	RSD (%)	Median	Min	Max	n	
Analgesic-antiinflammatory	Dextropropoxyphene	0.0273	20	0.0270	0.0220	0.0330	3	100	0.0523	27	0.0560	0.0370	0.0640	3	100
Analgesic-antiinflammatory	Diclofenac	1.34	83	0.997	0.105	4.11	91	81	0.680	82	0.420	0.0350	1.95	101	85
Analgesic-antiinflammatory	Ibuprofen	14.6	149	3.20	0.170	83.5	101	97	1.96	177	0.800	0.0020	24.6	109	93
Analgesic-antiinflammatory	Ketoprofen	1.03	117	0.340	0.0800	5.70	55	73	0.325	101	0.210	0.0400	1.62	53	73
Analgesic-antiinflammatory	Mefenamic acid	1.73	52	1.70	0.136	3.20	41	100	1.14	57	1.00	0.0900	2.40	41	100
Analgesic-antiinflammatory	Naproxen	26.4	343	6.00	1.79	611	45	96	1.89	245	0.880	0.170	33.9	53	87
Analgesic-antiinflammatory	Paracetamol	80.0	152	26.0	5.53	292	5	100	/	/	/	/	/	/	/
Antibiotic	Azithromycin	0.260					6	100	0.138					6	100
Antibiotic	Ciprofloxacin	0.413	27	0.430	0.180	0.571	20	83	0.0723	27	0.071	0.0450	0.140	29	91
Antibiotic	Clarithromycin	0.647					6	100	0.359					6	100
Antibiotic	Erythromycin	0.108	33	0.113	0.0710	0.141	3	100	0.212	34	0.202	0.145	0.290	3	100
Antibiotic	Levofloxacin	0.552					6	100	0.301					6	100
Antibiotic	Norfloxacin	0.438	12	0.433	0.343	0.515	18	100	0.0608	37	0.0515	0.0390	0.120	26	100
Antibiotic	Roxithromycin	0.0620	62	0.0640	0.0250	0.117	5	100	0.0496	27	0.0450	0.0360	0.069	5	100
Antibiotic	Sulfamethazin	0.333	91	0.210	0.110	0.680	3	43	/	/	/	/	/	/	/
Antibiotic	Sulfamethoxazole	0.342	114	0.157	0.0200	1.25	10	71	0.115	85	0.0700	0.0180	0.320	11	73
Antibiotic	Tetracyclin	0.457	43	0.465	0.240	0.790	6	86	0.282	135	0.115	0.0500	0.850	4	67
Antibiotic	Trimetoprim	0.449	94	0.281	0.0800	1.30	10	100	0.118	120	0.0600	0.0200	0.550	27	93
Anti-epileptic	Carbamazepin	0.968	61	0.732	0.100	1.90	64	100	0.674	68	0.520	0.150	2.30	63	100
Antifongic	Clotrimazole	0.0290	18	0.0310	0.0230	0.0330	3	100	0.0170	52	0.0140	0.0100	0.0270	3	100
Antineoplastic, cytostatic	Tamoxifen	0.170	23	0.153	0.143	0.215	3	19	0.238	49	0.199	0.146	0.369	3	19
Betablocker	Atenolol	0.0300					1	100	0.154	44	0.150	0.0100	0.380	18	100
Betablocker	Bisoprolol	/	/	/	/	/	/	/	0.709	68	0.637	0.303	1.43	18	100
Betablocker	Metoprolol	0.160					1	100	0.338	55	0.373	0.0100	0.688	37	97
Betablocker	Propranolol	0.0747	41	0.0650	0.0500	0.119	4	100	0.341	54	0.381	0.0100	0.615	24	100
Contrast product	Iopromide	4.49	75	5.22	0.0260	7.50	4	57	5.68	71	6.58	0.250	9.30	4	57
Disinfectant	Triclosan	0.380					1	100	0.150	48	0.130	0.0700	0.430	19	100
Hormone	17 β -estradiol	0.0074	58	0.0063	0.0015	0.0172	36	100	0.0008	110	0.0006	0.0001	0.0031	9	64
Hormone	17 β -ethinylestradiol	0.0042	237	0.0019	0.0004	0.0700	70	91	0.0009	120	0.0005	0.0002	0.0050	33	59
Hormone	17 β -estradiol	0.0222	78	0.0186	0.0025	0.125	108	100	0.0028	165	0.0015	0.0003	0.0300	63	74
Hormone	Estril	0.115	112	0.0695	0.0146	0.660	36	100	0.0131	365	0.0014	0.0004	0.275	33	92
Hormone	Estrone	0.0672	95	0.0600	0.0024	0.670	109	100	0.0209	121	0.0100	0.0006	0.0950	79	93
Lipid regulator	Bezafibrate	2.44	93	2.00	0.100	7.60	25	100	0.816	168	0.250	0.0200	4.80	21	78
Lipid regulator	Gemfibrozil	1.63	69	1.40	0.700	3.00	4	25	0.564	59	0.600	0.0600	1.34	21	70
Metabolite	Carbamazepin-10OH	0.0222					3	100	0.0325					3	100
Metabolite	Carbamazepin-2OH	0.0590					3	100	0.0704					3	100
Metabolite	Carbamazepin-3OH	0.0554					3	100	0.0692					3	100
Metabolite	Carbamazepin-DiOH	1.001					3	100	1.08					3	100
Metabolite	Carbamazepin-EP	0.0392					3	100	0.0191					3	100
Metabolite	Clofibric acid	0.294	55	0.250	0.0150	0.651	40	70	0.150	46	0.152	0.0420	0.230	24	55
Metabolite	Erythromycin-H2O	0.545	87	0.455	0.0700	1.20	4	67	0.220	52	0.270	0.0900	0.300	3	50
Metabolite	Salicylic acid	212	81	170	16.0	606	16	100	2.50	86	2.80	0.300	4.80	5	45
Personal care product	Galaxolide	2.51	51	3.06	0.790	4.443	9	100	0.642	32	0.600	0.451	1.08	9	100
Personal care product	Tonalide	0.990	50	1.02	0.210	1.69	8	100	0.162	11	0.160	0.144	0.200	8	100
Vasodilator	Pentoxifyllin	/	/	/	/	/	/	/	0.533	11	0.500	0.500	0.600	3	30

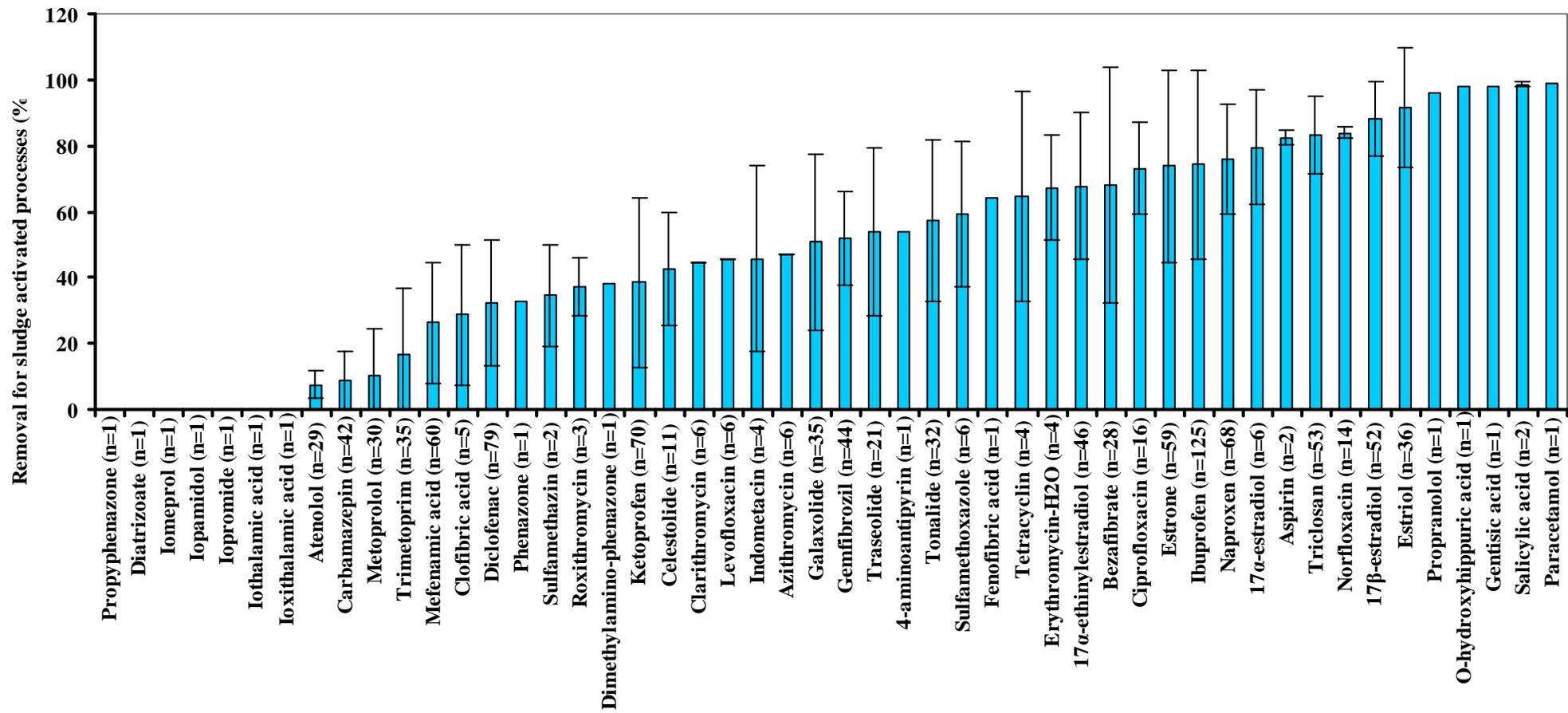


Figure 1: Mean removal efficiency (%) and relative standard deviation for pharmaceuticals and personal care products in wastewater treatment plants with activated sludge processes.

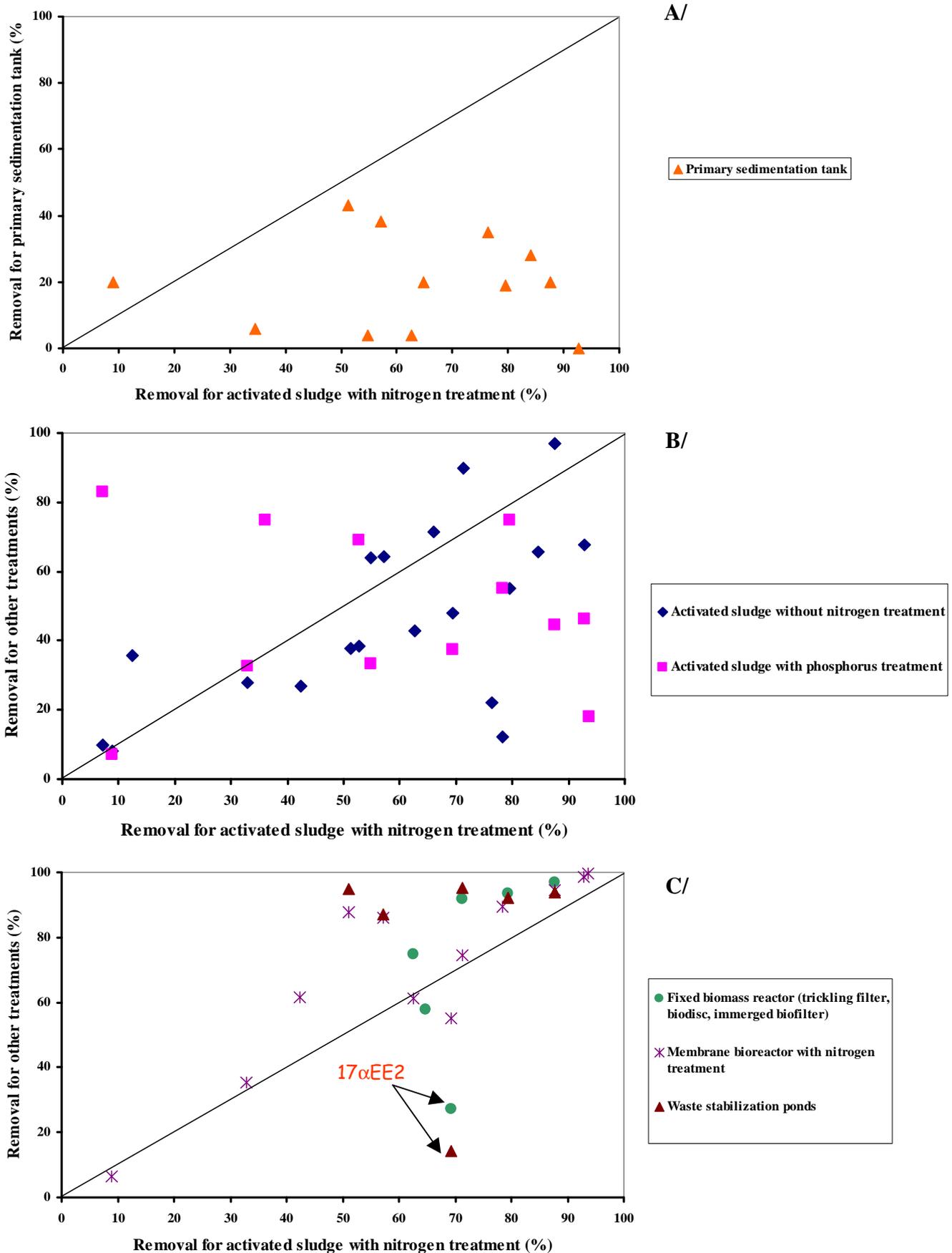


Figure 2: Comparison of removal efficiency (%) obtained for wastewater treatment plants with activated sludge process with nitrogen treatment (x-axis) and for wastewater treatment plants with other treatment processes (y-axis); each point represents mean removal calculated for one molecule.