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The significance of different health institutions and their respective contributions of active pharmaceutical ingredients to wastewater

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ABSTRACT

Active pharmaceutical ingredients (APIs) have been frequently found in the environment. It is, however, still not quite clear who is mainly responsible for API emissions. Hospitals have been considered to be the main contributing point sources for wastewater (WW) discharge of APIs. However, recent studies have shown that the contribution of hospitals to the input of APIs into the aquatic environment is quite low. Due to demographic change and the increase of psychiatric diseases, health institutions (HIs) such as psychiatric hospitals and nursing homes are likely to be important sources as well, but no data is available in this respect. This study aims to assess the impact of HIs and to provide a methodology to measure their respective contributions. Drawing on pharmaceutical consumption data for the years 2010, 2011, and 2012, this study identified API usage patterns for a psychiatric hospital (146 beds), a nursing home (286 inhabitants), and a general hospital (741 beds), the latter of which comprises three separate locations. All the HIs are located in two sub-regions of a county district with about 400,000 citizens in southwestern Germany. A selection of neurological drugs was quantified in the sewer of these facilities to evaluate the correlation between consumption and emission. The API contribution of HIs was assessed by comparing the specific consumption in the facilities with the consumption in households, expressed as the emission potential (I_{EP}). The study shows that the usage patterns of APIs in the psychiatric hospital and the nursing home were different from the general hospital. Neurological drugs such as anticonvulsants, psycholeptics, and psychoanaleptics were mainly consumed in the psychiatric hospital and the nursing home (74% and 65%, respectively). Predicted and average measured concentrations in the effluent of the investigated HIs differed mostly by less than one order of magnitude. Therefore, the consumption-based approach is a useful method to assess usage patterns of APIs in HIs and to predict their respective contributions to WW. The national contribution of HIs on total WW discharge of APIs compared to households was very low. Only the results for the sedative clomethiazole in general hospitals as well as the antidepressant moclobemide and the antipsychotic quetiapine for the nursing homes were found to deserve some attention. The regional comparison showed that in sub-regions with a comparably higher density of HIs, the allocated facilities could be seen as point sources emitting particular APIs. However, in general, the bulk of the consumed pharmaceuticals to WW discharge has to be attributed to households.

1. Introduction

In many studies, active pharmaceutical ingredients (APIs), contained in human pharmaceuticals, have been found in the environment in every possible country, with wastewater (WW) being the primary entry route (Halling-Sørensen et al., 1998; Klosterhaus et al., 2013; Langford and Thomas, 2009; Nikolaou et al., 2007; Verlicchi et al., 2012a). Studies have identified health institutions (HIs) such as hospitals as main polluters and tried to measure their environmental input of APIs (Escher et al., 2011; Gupta et al., 2009; Verlicchi et al., 2012b). Several studies reported that the contribution is depending on the bed density of HIs in the investigated area (Ort et al., 2010; Verlicchi et al., 2012b). Other studies showed that hospitals cannot be seen as a main source for APIs in the environment (Heberer and Feldmann, 2005; Kümmerer and Henninger, 2003; Schuster et al., 2008). By means of a

Abbreviations: API, Active pharmaceutical ingredient; ATC code, Anatomical therapeutical chemical code; AVR, Arzneiverordnungs-Report; DDD, Defined daily dose; HI, Health institution; I_{EP}, Emission potential; HOSP, Investigated general hospital, consisting of three locations; MAIN, Biggest location of the general hospital HOSP; MDL, Method detection limit; MEC, Measured environmental concentration; MQL, Method quantification limit; MWWC, Measured wastewater concentration; NH, Investigated nursing home; OPHT, Medium location of the general hospital HOSP; ORTH, Smallest location of the general hospital HOSP; PEC, Predicted environmental concentration; PSY, Investigated psychiatric hospital; PWWC, Predicted wastewater concentration; SHI, Statutory health insurance; STP, Sewage treatment plant; V_{DDD}, Specific daily dose defined for respective APIs; WW, Wastewater.

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mass balance, Kümmerer and Henninger (2003) identified households as the main contributors in terms of total environmental input of antibiotics. Le Corre et al. (2012) came to the same conclusion by evaluating the consumption-based contribution of all consumed APIs emitted from selected hospitals in comparison to the entire national consumption in Australia.

Data on the emission of APIs from HIs other than hospitals are, however, still not available, and psychiatric hospitals and nursing homes in particular have rarely been investigated as point sources for API emission. It is, however, necessary to understand their impact more clearly, as the importance of psychiatric hospitals will increase in the future, because the prevalence of mental diseases is associated with the increasing mental pressure in a meritocratic society (Janssens et al., 2014). Moreover, the increasing importance of mental diseases is also associated with demographic change, which is likely to make nursing homes even more important (Laidlaw and Pachana, 2009). In Germany, for example, the number of cases treated in psychiatric hospitals and people living in nursing homes has increased consecutively by about 13% between 2005 to 2011 (Federal Health Report Germany, 2014a, 2014b). Despite these significant developments, there is a considerable lack of information about the usage patterns of APIs in these facilities. Escher et al. (2011) described the usage patterns of a psychiatric center in Switzerland, but the authors could not provide a general conclusion concerning the contribution of APIs.

Many studies have already discussed how to determine environmental concentrations and, accordingly, the emission sources of APIs in the environment. In general, it is possible to model concentrations in the environment (predicted environmental concentration (PEC)) or to measure concentrations (measured environmental concentration (MEC)) (Johnson et al., 2008; Liebig et al., 2006). In some studies, analytical monitoring of API concentrations in receiving waters is considered to depict the actual situation in the environment (Al Aukidy et al., 2012). However, Le Corre et al. (2012) claimed that analytical determination is not always a suitable approach to determine the importance of APIs in terms of environmental impact, because analytical determination is often limited to the availability of suitable sampling sites. Likewise, samples are often not representative for the study area. As a result, this approach can lead to results that either overestimate or underestimate the contribution of different emission sources. In contrast to monitoring, the prediction of concentrations makes it possible to consider longer time periods, but this method is still not able to depict the actual situation. Therefore, recent studies have focused on the comparison of PEC and MEC illustrating limitations for both approaches. Mullot et al. (2010) compared PEC and MEC in hospital effluent and the receiving sewage treatment plant (STP), and they noted that there is a strong correlation between PEC and MEC when it comes to hospital WW. In contrast, Coetsier et al. (2009) focused on concentrations in STPs and concluded that PEC gives a first approximation, but MEC should be preferred. Verlicchi et al. (2014) revealed high variations between PEC and MEC in surface water. The authors noted that predicted concentrations are just theoretical values. Nevertheless, monitoring campaigns over a long period would become too complex to be feasible.

In this article (i) pharmaceutical usage patterns of APIs in a psychiatric hospital, a nursing home, and a general hospital are presented to determine emitted APIs of concern. Additionally, (ii) the method applicability of a consumption-based approach to identify emitted APIs from HIs was assessed by comparing PEC and MEC. Moreover, (iii) the respective contributions of APIs emitted to WW from such HIs in comparison to households were determined by means of the emission potential I_{EP} (national and regional scales). To meet these objectives, pharmaceutical consumption data of the HIs under consideration for the years 2010, 2011, and 2012 are presented and analyzed.

2. Material and methods

2.1. Calculations

2.1.1. Data sets and study site

In this study, a hospital (HOSP) with three locations (MAIN, OPHT, ORTH) was used to analyze the usage patterns of APIs. HOSP is located in southwestern Germany. With its three locations, it is classified, according to the Federal Statistical Office, as a general hospital (Federal Health Report Germany, 2014c). It is the largest part of a clinic association located in two sub-regions of a county with 400,000 citizens (Fig. 1). 2300 people are employed to treat approximately 30,000 cases each year. MAIN is the biggest location of HOSP and hosts patients with a focus on gastroenterology, general pediatrics, general surgery, nephrology, neurology, obstetrics, radiology, and urology. Data for every consumed pharmaceutical was collected to allow for a comparison to the psychiatric hospital and the nursing home. For the other two HOSP locations, data was collected on the most important 75% of pharmaceuticals in terms of number of prescriptions. The medium-sized location OPHT is located in the same region like MAIN. Its main focus is on cardiology, oncology, ophthalmology, pulmonology, and radio oncology. The smallest location ORTH is geared to orthopedic surgery and orthopedic rheumatology, and contains a small ward for general internal medicine.

The study also investigated the biggest psychiatric hospital (PSY) in the study region with 146 beds and approximately 1500 medical cases per year. PSY provides treatment for adults and juveniles, and it has three departments: psychiatric, psychotherapeutic, and psychosomatic. PSY is classified under the category 'other hospitals with exclusive psychiatric, psychotherapeutic or psychiatric, psychotherapeutic and neurologic beds' (Federal Health Report Germany, 2014d). In addition to a complete list of neurological drugs, data on the most important 75% of pharmaceuticals in terms of number of prescriptions consumed at this institution was collected.

With its 286 inhabitants, the nursing home (NH) under consideration is embedded in the clinic association of HOSP. NH provides care for the elderly, people with psychiatric disorders, and people suffering from alcoholism. In NH, data on every pharmaceutical was collected due to the availability of different raw data.

The data sets for each facility included the units consumed per pharmaceutical (HOSP, PSY) and the number and size of the delivered pharmaceutical boxes (NH) for the years 2010, 2011, and 2012. Data sets were obtained from the hospital pharmacy of HOSP and, in the case of NH, from the delivering public pharmacy. The entire data table comprised 45,343 entries in total.

In Table 1, the corresponding variety of entries per facility is presented together with the information about the capacity, treated cases/inhabitants, and water consumption of the facilities.

Data on the consumption of APIs in households in Germany, as defined daily doses (DDDs), was taken from the annually published report about prescriptions of pharmaceuticals in Germany, the so-called Arzneiverordnungs-Report (AVR) (Schwabe and Paffrath, 2011, 2012, 2013). AVR contains information on all pharmaceuticals prescribed at public expense in doctors' offices in Germany. Hence, it represents the overall consumption of pharmaceuticals for people insured by the statutory health insurance (SHI) in households and in nursing homes.

Two regions were chosen to measure the contribution of APIs. These two regions were classified according to the STP that processes the WW. The schematic constitution of the public sewer system is shown in Fig. 1. In Region 1, 85,000 citizens are connected to the STP. Around six million cubic meters of WW is treated every year at this site. Two facilities of the general hospital HOSP (MAIN and OPHT) and PSY are located in the same region. Region 2, which is adjacent to Region 1, with 13,000 citizens and WW treatment of one million cubic meters per year, is smaller. ORTH and NH are located in this region.