

BEST PRACTISES IN THE MANAGEMENT OF HOSPITAL EFFLUENTS

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ABSTRACT

In the last decade, greater attention has been paid to the presence in the water of emerging contaminants (including pharmaceutical and personal care products, pesticides, flame retardants...), that are quite often unregulated compounds. Hospitals are one of the most important sources of pharmaceutical compounds (PhCs) in a concentrated area and, together with households and industries, can be seen as significant urban area hotspots for discharging these contaminants into the sewer network and surface waters, with a potential impact on ecosystem.

Hospital wastewaters (HWWs) are composed of the effluents of different services: kitchen, internal laundry, heating and cooling systems, laboratories, radiology departments, outpatients departments, transfusion centres and wards. By law, HWWs are often considered to be of the same pollutant nature as urban wastewaters (UWWs), and so they are generally discharged into sewage networks, collected at a wastewater treatment plant (WWTP) and treated along with UWWs. WWTPs were originally built, and more recently upgraded, with the aim of removing C, N and P compounds: the pollutants regularly arriving at the WWTP in concentrations to the order of mg/L.

This paper analyses the differences between the wastewater from a hospital and an urban settlement in terms of hydraulic load as well as pollutants load and concentration on the basis of experimental investigations and literature data. Then it discusses if is correct to consider these two effluents of the same pollutant nature and if/when HWWs could be conveyed to a municipal WWTP for cotreatment with UWWs. Moreover it discusses the strategies in treating hospital flow rate (on site or off site, dedicated treatment or cotreatment at a municipal WWTP) on the basis of the hospital pollutant and hydraulic loads and finally it presents the most adequate treatment for HWWs on the basis of the recent results of the researches on the removal of PhCs. Furthermore a case study of the management of the effluent from a large hospital in a small town is also provided and discussed.

1 INTRODUCTION

During recent years, the issue of hazardous substances in wastewater (WW) has become a major concern with respect to both human health and the environment. This has lead to the launch of several studies into the monitoring of urban wastewaters (UWWs) (among them: Yu et al. 2006; Lishman et al. 2006; Santos et al. 2007; Terzic et al. 2008). However, few studies have yet been devoted to the monitoring of hospital effluents in terms of either conventional pollutant or micropollutant load (Boillot et al.

2008; Duongo et al. 2008; Suarez et al. 2009).

With few exceptions, hospital wastewaters (HWWs) are considered to possess the same pollutant load as UWWs, and are therefore discharged into the same sewage network and conveyed for cotreatment at the nearest municipal wastewater treatment plant (WWTP).

Nevertheless, HWWs contain a great variety of toxic or persistent substances, such as pharmaceutical compounds (PhCs), radionuclides, heavy metals, solvents and disinfectants. These substances, products of laboratory and research activities as well as general hospital activity and excretion of medicines, may be present in a wide range of concentrations, while they are not generally present in large quantities in UWWs.

Most PhCs belong to the group of the so-called *emerging contaminants* i.e. pollutants that are quite often unregulated as yet but may be candidates for future regulation, depending on the results of research monitoring their occurrence and assessing their potential effects on health (GWRC 2008).

Once PhCs have been administered, their active components are metabolized in the body, but only to a certain extent. The unmetabolized active substances are excreted, largely in the urine (55-80 % of the total with few exceptions, as reported by (Jjemba 2006 and Ternes and Joss 2006) and partially in the faeces, either as the unchanged substance, as a mixture of their metabolites, or conjugated with an inactivating compound attached to the molecule (Lienert et al. 2007), thereby entering the water cycle. Although many of these PhCs are specifically consumed in hospitals, a fraction of the administered dose could be excreted at home by outpatients and thereby enter the municipal sewage system. These compounds include anti-neoplastics, such as ifosfomide and cyclophosphamide, or contrast media like iopamidol or iopromide.

In the last decade, special attention has been paid to PhCs for various reasons: they are continuously emitted into the environment via effluents from WWTPs, and their high transformation/removal rates are counterbalanced by their continuous introduction into the environment (Barcelò, 2003). Furthermore, as they are developed with the intention of provoking a biological response, they need to be persistent in order to avoid inactivation of the compound before it can exert its therapeutic effect. Moreover, they need to be lipophilic in order to be able to pass through human cell membranes.

Recent environmental risk assessments have shown that the concentrations of pharmaceutical and personal care products (PPCPs) in aquatic environments may exceed their predicted no-effect concentrations (PNEC) (Stuer-Lauridsen et al. 2000; Santos et al. 2007). Furthermore, although the detection of multiple contamination is common, little is known about the potential interactive effects, such as synergistic or antagonistic toxicity, that may result from complex mixtures or metabolites (Kolpin et al. 2002). Thus, the wide variety of PhC chemical structures, combined with their excellent water solubility, their surface-active nature and the persistence of some of their known metabolites, make them a group of environmental pollutants whose behaviour need to be promptly addressed (Furhacker 2008).

This paper analyses the differences between the wastewater from a hospital and an urban settlement in terms of hydraulic load as well as pollutants load and concentration on the basis of experimental investigations carried out on two different healthcare structures and the catchment areas. Then it discusses if it is correct to consider these two effluents of the same pollutant nature and if/when HWWs could be conveyed to a municipal WWTP for cotreatment with UWWs. Moreover it discusses the strategies in

treating hospital flow rate (on site or off site, dedicated treatment or cotreatment at a municipal WWTP) on the basis of the hospital pollutant and hydraulic loads and finally it presents and discusses the most adequate treatment for HWWs on the basis of the recent results of the researches on the removal of PhCs. Furthermore a case study of the management of the effluent from a large hospital in a small town is also provided and discussed.

2 MATERIALS AND METHODS

Experimental investigations were carried out between 2007 and 2010 on the effluents of two hospitals of different size in the Province of Ferrara, Northern Italy (44°83'N and 11°62'E), in order to evaluate average hospital flow rate and specific hydraulic load and to characterize the effluents in terms of PhCs and macropollutants. At the same time the influent to the large WWTP of the town of Ferrara was monitored with respect to the PhCs.

2.1 Experimental

Hospital A – It is a medium size hospital with 300 beds, 650 people of the medical staff working in twelve main wards. It is placed 30 km far from Ferrara, in the town of Lagosanto (5000 inhabitants), in a coastal and tourist area, densely populated in summertime. Its effluent is directly discharged into the public combined sewage and conveyed to a small WWTP in Lagosanto (design capacity 5500 p.e.) where it is co-treated with the local UWWs. Hospital effluent has an average flow rate of about 160 m³ d⁻¹, resulting in a specific water consumption of about 550 L bed⁻¹ d⁻¹. The average WWTP total influent flow rate is about 1360 m³ d⁻¹ and the hospital flow rate corresponds to the 12 % of the total influent.

Hospital B and Ferrara WWTP – It is a large size hospital with 900 beds, 2000 people of the medical staff and more than 50 between wards and departments. It is placed in the centre of the town of Ferrara and its effluent is directly discharged into the combined sewage network and conveyed to the Ferrara WWTP (design capacity 120 000 p.e.) and co-treated with the UWWs. Average flow rate from hospital A is about 603 m³ d⁻¹, corresponding to a specific water consumption of about 670 L bed⁻¹ d⁻¹. The average urban influent flow rate to the WWTP is about 28 000 m³ d⁻¹, hence the hospital contributes for the 2 % to the influent hydraulic load.

2.2 Investigated parameters

Water consumptions. An in-depth literature survey has been carried out in order to compare hospital water consumption in the different countries with water consumption of the two healthcare structures under study. Comparison was made also with respect to the specific consumption of other kinds of communities (hotels, schools, campings, factories...), with respect to the single user (customer, student, guest, workers or employee...).

Macropollutant parameters: pH, BOD₅, COD, NH₄⁺, SS, total P, E. coli, chlorides, surfactants were investigated on the final effluent of Hospital A on 13 instantaneous water samples withdrawn in dry period (only 8 for BOD₅) between May 2007 and March 2008. Furthermore, Hg was also investigated in the same 13 water samples. Analysis of all the monitored parameters were performed according to the methods

described in IRSA-CNR (1994).

Micropollutant parameters: 73 different PhCs were investigated on the effluent of the two hospitals and in the influent of Ferrara WWTP (the number *n* of withdrawn and analysed samples varied between 3 and 7 depending on the WW). PhCs under study belong to the 12 different therapeutic classes reported in Table 1. They were selected for their high human consumption and their occurrence and ubiquity in the aquatic environment, according to the information found in the scientific literature.

Analysis of the 73 PhCs were performed on 4-hour composite samples, withdrawn in dry periods between September 2009 and March 2010. The corresponding analytical method is based on the simultaneous extraction of all target compounds by Solid Phase Extraction (SPE), using a hydrophilic-lipophilic balanced polymer followed by liquid chromatography tandem mass spectrometry, using a hybrid triple quadrupole-linear ion trap mass spectrometer (QqLIT) as reported in Gros et al., (2009 and 2010).

Table 1. Investigated pharmaceutical compounds grouped according to their therapeutic class.

THERAPEUTIC CLASS	COMPOUNDS
Analgesics and Anti-inflammatories	Acetaminophen, Codeine, Diclofenac, Ibuprofen, Indomethacin, Ketoprofen, Mefenamic acid, Naproxen, Phenazone, Phenylbutazone, Propyphenazone, Salicylic acid
Antibiotics	Azithromycin, Chloramphenicol, Chlortetracycline, Ciprofloxacin, Clarithromycin, Danofloxacin, Doxycycline, Enoxacin, Enrofloxacin, Erythromycin, Josamycin, Metronidazole, Nifuroxazide, Norfloxacin, Ofloxacin, Oxytetracyclin, Roxithromycin, Spiramycin, Sulfadiazine, Sulfamethazine, Sulfamethoxazole, Tetracycline, Tilmicosin, Trimethoprim, Tylosin A
Anti-diabetic	Glibenclamide
Anti-hypertensive	Enalapril, Hydrochlorothiazide, Lisinopril
Barbiturates	Butalbital, Pentobarbital, Phenobarbital
Beta-agonists	Clenbuterol, Salbutamol
Beta-blockers	Atenolol, Betaxolol, Carazolol, Metoprolol, Nadolol, Pindolol, Propranolol, Sotalol, Timolol
Diuretic	Furosemide
Lipid regulators	Atorvastatin, Bezafibrate, Clofibric acid, Fenofibrate, Gemfibrozil, Mevastatin, Pravastatin
Psychiatric drugs	Carbamazepine, Diazepam, Fluoxetine, Lorazepam, Paroxetine
Receptor antagonists	Cimetidine, Famotidine, Loratadine, Ranitidine
Antineoplastic	Tamoxifen

3 WATER CONSUMPTION IN HOSPITALS AND OTHER KINDS OF COMMUNITIES

The quantity of water required by hospitals on a daily basis is invariably large and dependent upon the various activities performed within, as well as the range of services they provide. Likewise, the quantity of WWs produced by a hospital also depends on several factors: bed numbers; hospital age; access to water; general services present inside the structure (kitchen, laundry and air conditioning); number and type of wards, departments and units; institutional management policies and attention to safeguarding the environment; climate; and cultural and geographic factors. Thus, there is no clear correlation between specific hospital consumption (expressed as L bed⁻¹d⁻¹) and hospital

size (that is the bed number), as shown by the dark circles reported in Figure 1 which refer to hospitals in different countries around the world (CTC 1994; Wangsaatmaja 1997; Laber et al. 1999; Chawatee 2002; Altin et al. 2003; Mohee 2005; Rezaee et al. 2005; Sarafraz et al. 2007; Boillot et al 2008; Duong et al. 2008; Guidelines of Emilia-Romagna Region, Italy 2009; Suarez et al. 2009; Mesdaghinia et al. 2009; Beier et al. 2010; Ort et al. 2010; Galletti 2011). Data are spread between 200 and 1200 L bed⁻¹ d⁻¹, with the highest values pertaining to industrialized countries and the lowest to developing nations, where consumption is generally around 200-400 L bed⁻¹ day⁻¹. In Fig. 1, crosses refer to the measured average flow rates for the hospitals A and B, while, white circles refer to the typical water-use values for institutional, commercial and recreational facilities: schools, factories, prisons, airport, offices, shopping centers, cinemas, hotels, campings, theaters. Their range of variability is included between few liters to 550 L user⁻¹ d⁻¹ (Metcalf & Eddy, 1991).

The hospital sewage network is in general separate for new structures, but for old buildings it is combined hence, in these cases, during rainy events the total effluent produced by the old hospital is much higher than in dry periods due to the collected rain flow rate. Also urban sewage network can be combined (mainly for old systems) or separate (for new urban settlements). These aspects do influence the choice in the management and treatment of hospital effluents as it will be discussed in the follow.

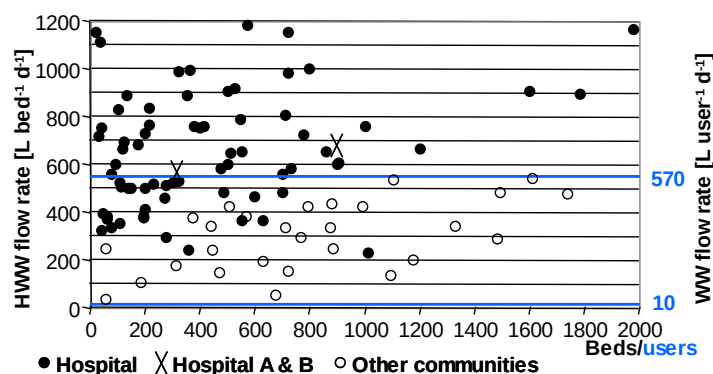


Figure 1. Water consumption per bed/user per day and for other communities with respect to hospital/community size (Adapted from Verlicchi et al. 2010b).

4 COMPARISON OF HOSPITAL AND URBAN EFFLUENTS IN TERMS OF QUALITY

The results of the investigations carried out on the two hospital effluents and the influent to the Ferrara WWTP are herein reported, together with a comparison with literature data. An in-depth description of these investigations are reported in Galletti (2011) and Verlicchi et al. (2011).

4.1 Macropollutants

Table 2 reports the average, minimum and maximum concentrations, as well as standard deviation and 95° percentile for the macropollutants investigated in the raw effluent of hospital A. The last two columns report the corresponding literature range of variability for HWWs and UWWs. It emerged that quite often, average values of BOD₅,

COD and SS are 2-3 times higher in HWWs than UWWs. The variability ranges for *E. coli* are not consistently different in the two WWs as found by Chitnes et al., 2004, Hartemann, 2005, Boillot et al. 2008. We did not investigated the presence of antibiotic resistance bacteria, but, it is important to underline that recently some Authors (Kummerer and Henninger 2003; Schwartz et al. 2003, Chitnes et al., 2004; Adelowo et al. 2008) found that in hospital effluents several bacterial strains carrying different resistance genes occur.

Table 2. Average, minimum and maximum values, S.D. and 95° percentile for the parameters investigated in the effluent of hospital A ($n = 8$ for BOD₅, and $n = 13$ for the other ones) together with variability ranges for HWWs and UWWs from literature data.

Parameter	average	min	max	S.D.	95° per	HWW range	UWW range
pH	7.1	6.96	7.34	0.2	7.3	6.9-9.18	7.5-8.5
BOD ₅ , mg/L	245	98	450	112	417	150-603	100-400
COD, mg/L	394	244	798	181	727	450-2300	500-600
NH ₄ , mg/L	29	21.8	46.1	8.9	43	10-55	12-45
SS, mg/L	125	66	300	71	246	120-400	120-350
P _{tot} , mg/L	5.8	3.7	7.6	1.3	7.5	3-8	4-10
Hg, µg/L	1.5	<0.5	3.05	1.1	2.9	0.04-5.03	< 0.5
<i>E. coli</i> , MPN/100 mL	1 10 ⁶	1.7 10 ⁵	2.4 10 ⁶	8.3 10 ⁵	2.2 10 ⁶	10 ³ -10 ⁶	10 ⁶ -10 ⁷
Chlorides, mg/L	94	85.9	102.7	7.3	102	80-400	30-100
Surfactants, mg/L	4.9	3.0	7.2	2.1	7.0	3-8	4-8

4.2 Micropollutants

The concentrations detected for the investigated PhCs in the two hospitals effluent and in the influent to the Ferrara WWTP are reported in Figures 2 and 3 as average, minimum and maximum values.

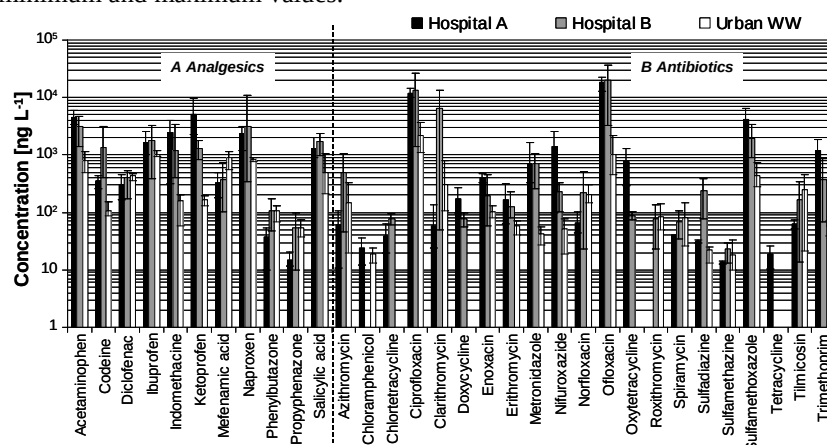


Figure 2 Range of concentrations of analgesics/anti-inflammatories and antibiotics in the effluents of two different-size hospitals and in the influent to Ferrara WWTP during the investigations.

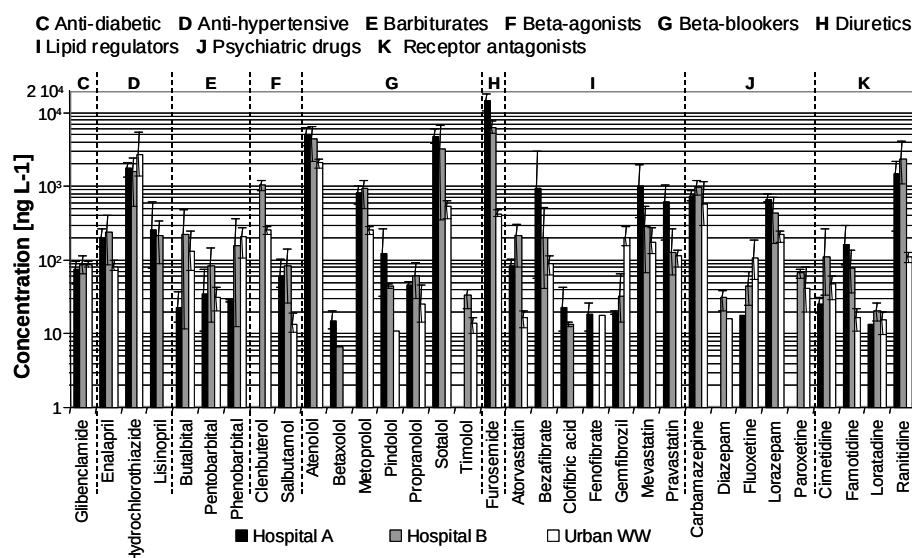


Figure 3 Range of concentrations of other PhCs in the effluents of the two hospitals and in the influent of the Ferrara.

65 compounds were detected in at least one sample of each WW, while 8 compounds were always below the specific limit of detection. Collected data show that concentrations in HWWs are quite often greater than those found in the urban influent, confirming available literature data.

To the best of our knowledge, the most critical therapeutic classes present in hospital wastewaters are antibiotics and anti-neoplastics. This focus has been spurred on by two main considerations. The first of these is the desire to reduce the risk of discharging great quantities of anti-bacterials into the environment, as this can significantly contribute to the development of antibiotic-resistant strains of bacteria (Hartemann et al. 2005, Lenz et al. 2007a, 2007b); the second is that different studies have shown that, owing to the presence of cytostatics and certain antibiotics like fluoroquinolones, hospital effluents can possess mutagenic properties and be toxic to bacteria (Hartmann et al. 1998; Jolibois and Guebert 2005, Ferk et al. 2009).

5 STRATEGIES IN MANAGING HWWS

Proper management of hospital effluent should take into consideration the characteristics of the catchment area in which the hospital is situated, i.e. (i) size of area, number of residents and non residents (p.e.), average and maximum urban flow rate, (ii) industrial activities present in the area (type, WW flow rate, adopted pre-treatments within the battery limits, final disposal of the effluent, cotreatment with other kind of WWs...), (iii) characteristics of existing WWTPs (nominal capacity, residual capacity, treatment sequence, authorized limits for the final discharge), (iv) characteristics of the receiving water body (hydraulic regime, auto-depurative capacity, irrigation, recreational and industrial uses...), (v) legal and regulatory constraints.

In case of cotreatment of HWW and UWW, it is important to evaluate the percentage of hospital flow rate with respect to the total WWTP influent flow rate (Verlicchi et al. 2010a). This value depends on hospital size (small size with < 300 beds, medium size with 300-700 beds and large size with > 700 beds), and on the size of the resident population in the urban centre. A representative situation is depicted in Fig. 3, where hospital and urban flow rates are plotted, respectively, against the number of beds and p.e. These flow rates are based on a specific water consumption of 700 L bed⁻¹ d⁻¹ for hospitals and 150 L p.e.⁻¹ d for resident populations. A large hospital of 900 beds without internal laundry, producing a daily flow rate equal to 630 m³ d⁻¹, has the same hydraulic load as an urban centre of 4200 p.e. If this hospital is situated in a large town (for instance 100,000 p.e., corresponding to 15,000 m³ d⁻¹) and its effluent is co-treated at the same WWTP, the hospital flow rate corresponds to $630/(630 + 15,000) \times 100 = 4$ % of the total WWTP influent. In contrast, if the same quantity of hospital effluent is collected in a small WWTP receiving UWWs from a 2000 p.e. urban centre (300 m³ d⁻¹), its percentage contribution to the total WWTP influent flow rate increases to $630/(630+300) \times 100 = 68$ %.

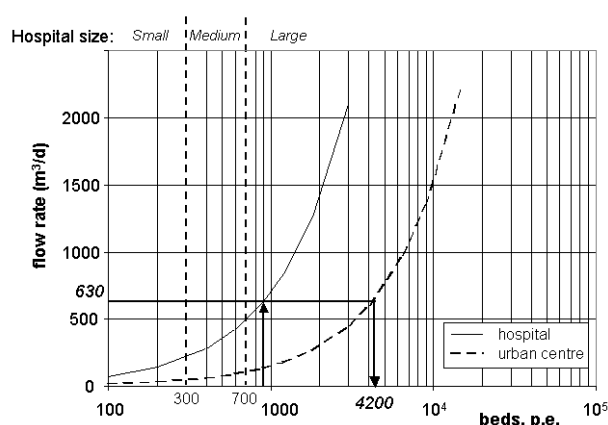


Figure 3 Flow rates for hospitals and urban centres of different sizes.

Hartemann et al. 2005 postulated that, if a hospital of 1000 beds has an internal laundry (hypothesis not always verified), it is as polluting as a town with a population of 10,000 people, meaning that its contribution to the influent of a cotreatment WWTP could be even higher than the figures cited.

However, it should be noted that the characteristics of the catchment area will be quite different from case to case. Thus, the parameter “number of beds per 1000 inhabitants”, also called the *bed density*, is used to give an idea of the resident population in the area surrounding the healthcare structure and to provide useful information about the pollutant load into the environment. For instance, if a large, 1000-bed hospital were situated in a town of 130,000 inhabitants, the bed density would be 7.7, while if it were placed near an urban settlement of 6000 inhabitants, the same parameter would become 167. In the first case, the hospital would not be the greatest source of PhCs, while in the second it would be the main contributor. According to published data, the value of the bed density may vary between 0.4 and 170 beds/1000

inhabitants (Heberer and Feldman 2005; Thomas et al. 2007; Feldman et al. 2008; Schuster et al. 2008; Ort et al. 2010; Verlicchi et al. 2010a).

Concerning the pollutant load, a mass balance of the most critical PhCs (for instance some antibiotics, the most administered analgesics/anti-inflammatories and the psychiatric drug carbamazepine, considered an anthropogenic marker in wastewaters) on a *local* level provides useful information about the contribution of the hospital effluent with respect to that of the catchment area. Hospital effluent contributes to the emission of the different PhCs to a different extent with respect to the UWWs generated by the surrounding catchment area, depending on the specific compound.

On the basis of our collected data we found that the highest hospital loads are for antibiotics (29 %), diuretics (29 %) and for receptor antagonists (38 %), while for the other classes, hospital contributes to a lower extent (1.9-9 %). The most consistent contributions by the large hospital effluent resulted for clarythromicine (77 %), ranitidine (59 %), ofloxacin (66 %), methronidazole (49 %) and furosemide (38 %).

According to Beier et al. 2011 hospital contribution can reach as high as 94 % for some antibiotics (ciprofloxacin), while according to Kummerer 2009, up to 25 % of the antibiotics administered in Germany are used in hospitals. Langford and Thomas 2009 evaluated the contribution of two medium/large size hospitals (600–1200 beds) in a large catchment area (610,000 p.e.) in Norway, for different PhCs. Only ciprofloxacin, present in HWWs in extremely high concentrations, contributed more than 38 % to the influent at the WWTP. The contribution of the other PhCs varied in the range: 0.5–10 %. A similar study was carried out by Ort et al. in 2010. These authors made an in-depth analysis of the fraction of 59 pharmaceutical residues in wastewater originating from a hospital (200 beds) and from its catchment area (45,000 inhabitants) discharged in a region of Australia. They found that five compounds (the lipid regulator atorvastatin, the anti-depressant citalopram, the anti-inflammatory diclofenac, the analgesic oxycodone, and the biocide triclosan) were only detected in HWWs, while 24 were detected neither in the HWW nor in the total WWTP influent. Only two substances, trimethoprim (18%) and roxythromycin (56 %), displayed a maximum observed hospital contribution of > 15 %. On average, the contribution of the hospital for the compounds investigated in both hospital and sewage treatment plant influents was small and fairly constant.

5.1 First screening in the management and treatment of HWWs

We think that the most adequate management and treatment of HWWs should be defined case by case on the basis of an in-depth analysis. The following steps can help decision makers and administrators in their evaluation in the choice of the best strategy to adopt for managing and treatment of HWWs.

1. Evaluate the characteristics of the catchment area, in terms of flow rate (including its probable expansion) and typology (only domestic, also industrial, zootechnic...).
2. Evaluate the characteristics of the receiving water body (range of variability of the flow rate, autodepurative capacity, insolation...final destination, further discharges...).
3. Evaluate the bed density for the current situation and for the short and long future.
4. On the basis of on site experimental campaigns and of literature data, evaluate the pollutant loads of HWWs and UWWs in terms of macropollutants as well as micropollutants along the year. Identify them for the catchment area and the hospital in the different seasons. Evaluate a mass balance for the most critical compounds or

therapeutic classes on a local basis.

5. Evaluate the characteristics of the nearest WWTP and the feasibility to convey the HWW there, for a *dedicated* and adequate treatment in the same placement area.

6. Avoid cotreatment. Adopt it only in case all the other possibilities are technically and economically NOT convenient or NOT feasible.

5.2 Suggested solutions for the management and treatment of HWWs

In general, a multibarrier system is the best choice in order to have different step able to remove or eliminate the different kinds of persistent compounds which require different operational conditions (aerobic, anoxic, anaerobic ones) to be efficiently removed.

A biological step is always necessary to remove carbonaceous fraction from the influent WW. The sequence of treatment should be designed with the possibility to be upgraded according to the most recent indications and suggestions by the experts. Plants must be reliable and “robust”. In the following the solutions we suggested on the basis of our knowledge and the most recent results of the published studies.

1. Source separation between urine and faeces. As pharmaceuticals are excreted to a great extent in urine, separation and unique treatment of urine would significantly reduce the loading of the wastewater.
2. Large hospital in a small catchment area. Verify that hospital sewage system is a separate one. For HWW adopt advanced biological and oxidation processes (AOPs), such as ultrafiltration membrane biological reactors (MBRs) and then ozone/UV, which also guarantee an efficient disinfection.
3. Large hospital in a densely populated catchment area. Verify the type of the sewer system for both hospital and urban settlement. Evaluate the treatment capacity of the existing municipal WWTP and evaluate the possibility to add a line dedicated to HWW. In case of cotreatment, upgrade the existing sequence of treatment in order to guarantee the removal of the persistent compounds: AOPs are the best available technologies.
4. Small hospital in a densely populated catchment area: evaluate the specific contribution of HWWs to the total due to HWW and UWW, in particular the most critical PhCs administrated in the health structure. Evaluate the technical and economical feasibility to adopt dedicated and specific treatments for HWWs. Evaluate advantages and drawbacks of cotreatment
5. Small hospital in a small urban catchment area: A local mass balance for micropollutants and macropollutants loads can provide useful information for the contribution of the different users. Furthermore, an environmental risk assessment of the expected final effluent and an analysis of the characteristics of the local receiving water body will guide in the choice of the sequence of advanced treatment (MBR, ozone, UV).
6. Basic treatment. In developing countries where also UWWs are scarcely treated and only few WWTPs are working, HWWs should be on site treated by adopting a basic sequence of treatment (pretreatment, biological treatment and disinfection) in order to safeguard the receiving water body from the spread of micropollutant and microorganisms. Municipal WWTPs will be conceived and then constructed taking into consideration the necessity to control the pollution due to hospital effluents. In this context, administrators and technicians will have to evaluate the possibility to

adopt a dedicated line for special WWs (including HWWs) in the same placement area of the municipal WWTP, especially in case of large size hospitals.

6 A STUDY CASE: A LARGE HOSPITAL IN A SMALL TOWN

The new hospital complex in Ferrara is situated six kilometres from the town in the first outskirts, in the small urban centre of Cona. It has a capacity of 900 beds and a staff of 2400, including medical, administrative and technical services, in addition to 250 university students and elderly people staying in the on-site accommodations. Due to the building growth connected with the hospital construction, the nearby urban centres (Cona and Gualdo) are under expansion and their estimated residential population is expected to climb to 1700 persons over the next years. In addition, there are local businesses and industries, corresponding to 500 p.e. Currently in this area, combined urban and industrial wastewaters (respectively UWWs and IWWs) are conveyed to a small WWTP at Gualdo designed for 1000 p.e. Treatment includes screening, primary sedimentation, conventional activated sludge treatment and disinfection. This WWTP is not adequate to treat all the wastewaters coming from the new hospital and the new urban development. A feasibility study has been carried out to compare different scenarios with the aim of highlighting the advantages and disadvantages of each design solution (Fig. 4).

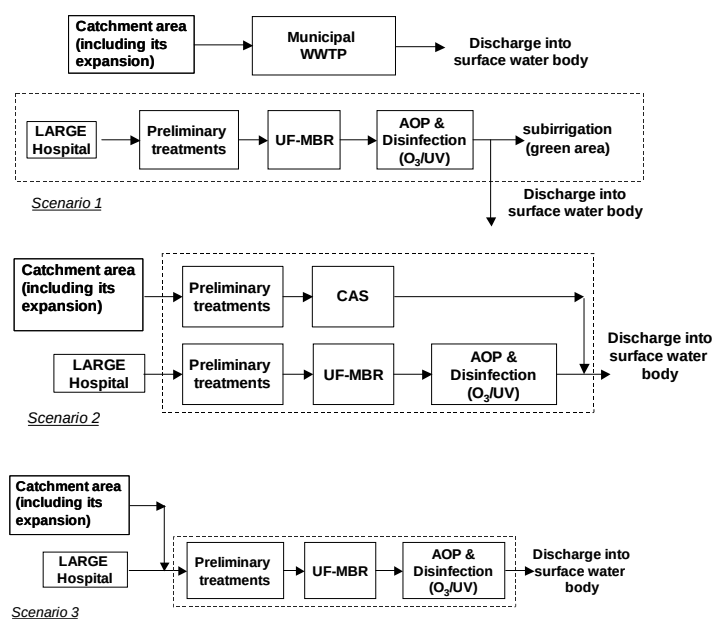


Figure 4. Different scenarios for the treatment of the effluent of the new large hospital in Ferrara.

The last option was selected for the treatment of hospital, urban and industrial wastewaters in the study site for the following reasons: (i) hospital flow rate will represent the greater part of the whole wastewater flow rate to be treated for the next 5-10 years, as the nearby urban centres will take longer to be completed; (ii) existing

overflows along the network for domestic and industrial sewage regulate the flow inside the pipes and guarantee a maximum flow rate at the WWTP; (iii) the sewage systems of the urban centres under expansion are separated and only blackwaters will be conveyed to the WWTP. Rain waters will be treated separately.

The adopted sequence of treatments is reported in Figure 5. Design parameters of the biological section result from the experimental investigation on the hospital effluent and on the MBR pilot plant previously described; those referring to ozonation/UV irradiation derive from literature specific data (Ternes and Joss, 2006). The average wastewater flow rate is about 60 m³/h.

Hospital effluent and urban-industrial wastewaters are pumped separately, then subjected to a screening and a biological treatment (dephosphoration-nitrification-denitrification) by an MBR (sludge retention time SRT= 30 d; biomass concentration of 8-10 kg/m³, ultrafiltration membranes with pores size of 0.01 mm, a surface flux of 15-25 L/m²·h). The permeate is subjected to an AOP by means of O₃ (7.5-10 mg O₃/L, contact time of 16 min) and UV (irradiation of 100 mJ/cm², exposure time of about 4-7 s).

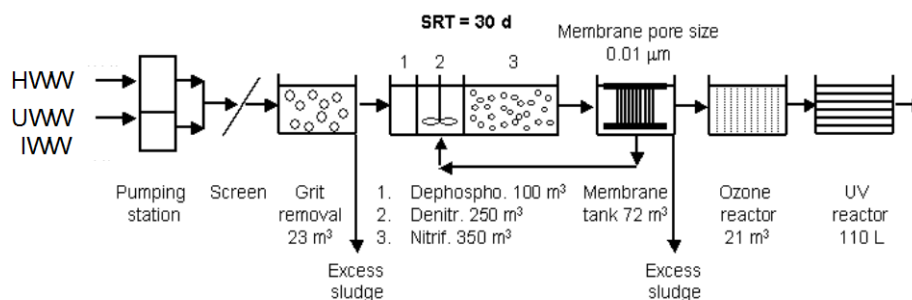


Figure 5 Sequence of treatment adopted for the large hospital situated in the small urban centre in the first outskirts of Ferrara.

For the sludge, technologies able to greatly reduce its production and disposal frequency have been adopted: first, an aerobic digestion; second, an ozonation (50 g O₃/kg TSS treated) of the digested sludge which reduces the excess sludge amount and favours oxidation of the PhCs absorbed into the solid phase, increasing the content of readily biodegradable COD, and third, a mechanical thickener completes the treatment.

On the basis of experimental investigations (Verlicchi et al., 2010a), concentrations in the influent and in the effluent of the MBR are those reported in Table 3., The final effluent, after AOP treatment, will have a better quality in terms of macro-pollutants as well as of PhCs (antibiotics, analgesics and anti-inflammatories) due to the combined action of ozone and UV on recalcitrant compounds and less biodegradable organic matter still present in the water. According to literature data (Boujou et al., 2008; Kasprzyk-Hordern et al., 2008; Radjenovic et al., 2009), their removal range is from 50-90%.

This produces an effluent of really high and constant quality, which is also able to meet the strict Italian limits for discharge into surface water bodies and with an adequate dose of ozone and radiation, legal limits for direct reuse will also be satisfied. Its receiving surface water body is a narrow canal with a modest autodepurative

capacity belonging to the local network, usually used for agricultural needs. The ability to guarantee a WWTP effluent of excellent quality reduces its impact on the environment.

Table 3 Main design parameters and final permeate quality

	Influent	Effluent
COD, mg/L	355	20
SS, mg/L	137	2
BOD ₅ , mg/L	164	9
N-NH ₄ , mg/L	25	2
Total P, mg/L	5	1
<i>E. coli</i> , CFU/100 mL	5·10 ⁵	5

6.1 Footprint and costs

The WWTP covers an area of 1,000 m², resulting in a specific area of 0.25 m²/p.e. Specific construction costs amount to 460 €/p.e. and 3.6 €/m³ for treated wastewater. Energy consumption amounts to 830 MWh/yr, resulting in an annual cost of 100,000_€. The reduction in the excess sludge production due to ozonization amounts to 100 tn/yr resulting in a gross economic output of 59-88 €/ton of sludge not disposed.

7 CONCLUSIONS

Hospital effluents are generally considered to possess the same pollutant load as UWWs, but this study and many others, have demonstrated that this is not the case. Indeed, HWWs tend to have higher concentrations of both macropollutants and micropollutants (PhCs, detergents, disinfectants, heavy metals...).

Hospitals require a significant quantity of water for the different activities and services taking place within the structure. In general, a hospital of 1000 beds with an internal laundry pollutes to the same extent as a town with a population of 10,000 p.e., although hospital effluents contribute to different extents to the emission of the different PhCs with respect to the UWWs generated by the surrounding area. Specifically, the proportion depends on the specific compound. On the basis of our collected data we found that the highest hospital loads are for antibiotics (29 %), diuretics (29 %) and for receptor antagonists (38 %), while for the other classes, hospital contributes to a lower extent (1.9-9 %). The most consistent contributions by the large hospital effluent resulted for clarythromicine (77 %), ranitidine (59 %), ofloxacin (66 %), methronidazole (49 %) and furosemide (38 %).

The quali-quantitative differences between HWWs and UWWs, focused in this study, underline that an in-depth analysis must be carried out in order to evaluate the contribution of the hospital in terms of macropollutants and micropollutants with respect to its catchment area. A multistep methodology is here presented and discussed in order to help administrators, technicians and politicians in their choices and planning.

A dedicated treatment for HWWs is always a good solution, especially in the case of a large hospital in a scarcely populated area. The treatment sequence that seems to be the most appropriate one is a multibarrier system with a combination of biological, physical and chemical mechanisms (ultrafiltration MBR followed by advanced oxidation processes by means of O₃/UV). In this way a combination of different

mechanisms can occur in the different treatment phase, giving the possibility to compounds with great differences in their chemical-physical characteristics to find operational conditions where they can be effectively removed.

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