Full-Scale Plants for Dedicated Treatment of Hospital Effluents

Sara Rodriguez-Mozaz, Daniel Lucas, and Damià Barceló

Abstract Hospital effluents are usually discharged in the municipal sewer system without any previous pretreatment. However, hospital wastewater contains a complex mixture of hazardous chemicals and harmful microbes, which can pose a threat to the environment and public health. Therefore, some efforts have been carried out in the last years with the objective of treating hospital wastewater effluents on-site before its discharge either in the sewer system or into the receiving natural water body. Several initiatives and case studies of full-scale wastewater treatment plants (WWTPs) implemented in hospitals are gathered together in this chapter. Different treatment train types were considered and reviewed, and the most common and efficient primary, secondary, and tertiary treatments applied were discussed. Several water quality parameters were monitored in the 23 studies comprised in this chapter for the performance assessment of the hospital wastewater treatment plants (HWWTPs). Special attention was paid to specific contaminants that are present at relatively high levels in hospital effluent such as antibiotics. In line with this, the spread and dissemination of antibiotic resistance from hospital and HWWTPs was considered an important topic to be addressed in this chapter.

Keywords Dedicated wastewater treatment, Full-scale WWTPs, Hospital effluents, On-site treatment, PhACs

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Contents

1 Introduction

Hospital wastewater is comparable with ordinary domestic wastewater plus a very special mixture of different pollutants such as pharmaceutical active compounds (PhACs), heavy metals, detergents, X-ray contrast media, and disinfecting agents [1] along with pathogenic microorganisms such as viruses, bacteria, fungi, protozoans, and helminthes [2, 3]. Hospital sewage can thus represent a threat to public health due to its potential toxicity, highly infectious potential, and its role in pathogen dissemination and in antibiotic resistance spread into the environment. Mixing between these effluents and drugs can indeed promote a selective pressure, capable of inducing innate microorganisms to a rapid adaptation to these fluctuating conditions through genome rearrangement [4]. Despite of this, hospital wastewater has long been treated along with urban wastewater, with the conventional wastewater treatment processes, which are designed for the removal of BOD (biological oxygen demand) and SS (suspended solids), but not for pathogens [5] or other micropollutants [6, 7].

There is not a specific directive or guideline for the management of hospital wastewater effluents in Europe, so member states apply their own legislation, evaluation, and selection criteria for hospital wastewater (HWW) quality and its management. However, national legal regulations, quite rarely, define how to manage and treat hospital wastewaters before its disposal (discharge in public sewage for treatment at a municipal WWTP or discharge into a surface water body) [8, 9]. In some countries (e.g., Spain and France), hospital facilities are considered industrial and therefore HWW should comply with certain characteristics before being discharged in the municipal wastewater treatment plant (WWTP), and very often a pretreatment is required. In some other countries (e.g., Italy), HWW can be directly discharged in the public sewer and conveyed to the municipal WWTP if it complies with specific characteristics established by the WWTP authority. Otherwise, it has to be pretreated. In contrast, in other countries (e.g., Germany) hospital wastewater is considered to be domestic or communal, and neither authorization nor specific characteristics are required [10]. The contribution of hospital facilities to the total volume uploaded in the municipal WWTP depends on many factors but can range between 0.2 and 2% of the total discharge treated in a municipal WWTP as calculated by Carraro et al. based on several studies worldwide [10]. However, in some occasions, a hospital can deliver up to 68% of total domestic WWTP influent, as reported in a hospital in Italy [11]. In China, the total number of hospitals has raised almost double in two decades, and in 2008 the volume of hospital wastewater generated corresponded to approximately 1% of total municipal wastewater [12].

Indicators required for assessment of hospital effluents quality are usually physicochemical parameters, macropollutants (NH_4, NO_x, oil and grease, tensioactives, phosphorous, chlorines, and others), and, in some rare cases, microbiological indicators (typically *E. coli*). However, a concern has emerged in the last years regarding substances and microorganisms that do not have a regulatory status such as antibiotic residues and specific pathogens, and none of them have a specific limitation before discharge in WWTPs or in surface water [10]. The common practice of co-treating hospitals and urban wastewaters jointly at a municipal WWTP is considered as an inadequate solution for the removal of compounds such as PhACs [13, 14] by many authors, because dilution of the hospital effluents would occur; it has been demonstrated that wastewater dilution is detrimental for the biological removal by conventional activated sludge (CAS) of some micropollutants such as PhACs [15, 16]. Therefore, the use of alternative wastewater treatments at the source point for this kind of effluents has been highly recommended by many authors [9, 13, 14, 16, 17]. Extensive research has been performed in the last year in the development of appropriate decentralized treatment for the hospital effluents as it has been reviewed lately by Verlicchi et al. [13]. However, the application of full-scale dedicated treatment of the effluents in hospitals has been only implemented in a limited number of places. The objective of this chapter is to review the existing studies about on-site full-scale hospital wastewater treatment plants. Trends concerning the most applied treatment train types, parameters monitored, geographical differences, as wells a future research trends are discussed in this chapter.

2 Discussion

In a recent review by Verlicchi et al. on the management of treatment hospital effluent, an overview of 48 peer-reviewed papers is presented assessing the efficacy of different treatment steps of hospital wastewater, comprising lab, pilot, and full-scale approaches [13]. Most of the investigations referred to pilot/lab scale plants (69%) and the remaining 31% to full-scale dedicated facilities; hence, there is still many research efforts dedicated to the optimization of the most appropriate treatment for each hospital. Aspects to take into account in the design and implementation of full-scale treatments are the wastewater characteristics (type and concentration of pollutants), environmental conditions, further use of treated wastewater, and technical and economic feasibility of the treatment.

Table 1 gives an overview of several research works reporting about full-scale dedicated treatments of hospital wastewater effluents. A total of 23 studies performed since 2004 till 2016 are listed in Table 1, which also provides

Table 1 Literature review about dedicated full-scale hospital wastewater treatment plants

Country	Hospital characteristics		Treatment train				Receiving system	Quality parameters evaluated	Reference
	Flow rate (m^3/day)	Patients (beds)	Primary treatment	Secondary treatment	Tertiary treatment	Disinfection			
Denmark	360–500	691		MBR MBR	GAC + O_3/H_2O_2 GAC	UV UV	Water body and sewer system	PhACs, antibiotic resistance, and pathogens	[18]
Germany	768	340		MBR			n.i.	PhACs (8)	[19]
Germany	768	340		MBR			n.i.	Conventional parameters: COD, TOC, AOX, NH_4, total P, *E. coli*, and *Enterococci*	[1]
Germany	768	340		MBR	O_3		n.i.	Endocrine activity	[20]
Germany	200	580		MBR	O_3 + PAC + sand filtration PAC + sand filtration		Water body	Micropollutants (including PhACs), integrons, toxicity	[21]
Netherlands	240	1,076		MBR			Sewer system	Micropollutants (including PhACs), integrons, toxicity	[21]
Netherlands				MBR	O_3 + GAC		Sewer system	PhACs, endocrine activity, microbial parameters, and conventional parameters	[22]

Italy		900		MBR	O_3	UV	n.i.	Conventional parameters: COD, BOD5, NH_4, turbidity, and *Escherichia coli*	[11]
Greece		800		CAS		Chlorination	UWWTP through sewer system	Conventional parameters: COD, BOD5, NO3, PO4 and TSS, and PhACs	[23]
Ethiopia	143	305	Septic tank	Oxidation ponds			Lake	Conventional parameters: COD, BOD5, P, PO4, total nitrogen, NH3, NO3, NO2 TSS, TDS, Cl, S2, total coliforms, and fecal coliforms	[24]
Saudi Arabia	904 622	300 215		CAS	Sand filtration	Chlorination	n.i.	PhACs	[25]
Iran		255–1,073		CAS		Chlorination	n.i.	Conventional parameters: COD, BOD5, DO, TSS, pH, NO2, NO3, PO4, Cl, and sulfate	[26]
India	50	319		CAS		Chlorination	Water irrigation of gardens of hospital	Genotoxicity and mutagenicity	[27]

(continued)

Table 1 (continued)

Country	Hospital characteristics		Treatment train				Receiving system	Quality parameters evaluated	Reference
	Flow rate (m^3/day)	Patients (beds)	Primary treatment	Secondary treatment	Tertiary treatment	Disinfection			
Nepal	20		Septic tank	Constructed wetlands				Conventional parameters: TSS, BOD5, COD, NH_4, PO4 2−, total coliforms, *E. coli*, *Streptococci*	[28]
China				MBR				Conventional parameters: COD, BOD5, NH3, TSS, bacteria, and fecal coliform	[7]
				MBR		Chlorination			
China	20			MBR			n.i.	Conventional parameters: COD, BOD5, NH_4, turbidity, and *Escherichia coli*	[29]
China		500–2,410		MBR Anaerobic oxic Oxidation ditch			n.i.	Antibiotics and corresponding ARGs	[30]

Vietnam[a]		220	Filtration	CAS		Not specified		Antibiotics	[31]
		520	Physical and chemical (not specified)	CAS			Environment (not specified)		
Republic of Korea			Flocculation		Activated carbon		River water and seawater	PPCPs	[32]
			Flocculation	CAS					
Brazil	190		Septic tank		Anaerobic filter		Water stream	Psychiatric drugs (5)	[33]
Brazil			Septic tank		Anaerobic filter		Water stream	Antibiotics (ciprofloxacin)	[34]
Brazil	219	2,000 patients		UASB	Anaerobic filter		Bay	Enteric viruses and hepatitis A	[35]
	432	22,000 patients		CAS		Chlorination	Lagoon		
Brazil	220	320		CAS		Chlorination	River and seawater through the rainwater network	Antibiotic resistance profiles of *Pseudomonas aeruginosa*, pH, conductivity, turbidity, dissolved oxygen, temperature, salinity, and chlorine	[3]

(continued)

Table 1 (continued)

Country	Hospital characteristics		Treatment train				Receiving system	Quality parameters evaluated	Reference
	Flow rate (m^3/day)	Patients (beds)	Primary treatment	Secondary treatment	Tertiary treatment	Disinfection			
Brazil	220	320		CAS		Chlorination	River and seawater through the rainwater network	*Pseudomonas aeruginosa* isolates and β-lactam-encoding genes	[36]

UASB upflow anaerobic sludge blanket, *PAC* powdered activated carbon, *GAC* granulated activated carbon, *CAS* conventional activated sludge, *MBR* membrane bioreactor, *PPCPs* pharmaceuticals and personal care products, *PhACs* pharmaceutical active compounds, *n.i.* not indicated

[a] Detailed description of the wastewater treatment plants was not available

information about the country where the study was conducted along with several details such as the size of the hospital, the treatment type applied in each case, as well as quality parameters considered to evaluate the efficiency of the treatment. Full-scale WWTPs for the treatment of hospital effluents have been implemented all over the world being Brazil, with seven manuscripts, the country with the highest number of studies about the topic, followed by China and Germany with three studies each, and the Netherlands with two. In other countries such as Denmark, Greece, Italy, Iran, Taiwan, Korea, Ethiopia, Saudi Arabia, India, Nepal, and Vietnam, just one study was reported in each of them. Most of the studies were carried out in developing countries, where for urban wastewater usually only basic sewage systems are operating, and, therefore, dedicated treatments are necessary to guarantee a safe treatment and disposal of hospital effluents. In addition, in the case of countries experiencing epidemics of enteric diseases, the on-site treatment, or at least pretreatment, of the wastewater before discharge into the municipal sewerage system should be considered to prevent and avoid the spread of disease outbreaks due to pathogens [10]. In contrast, in European countries, implementation of dedicated treatments and research efforts on the topic are driven by the awareness of the potential risk posed by hospital effluents and the need of reduce the load of emerging pollutants such as PhACs, which are present at higher concentrations in hospital effluents [9, 37]. In general, if the hospital is not connected with a public wastewater treatment, the facility should have an efficient on-site wastewater treatment [10]. Water scarcity and the need of water reuse for various requirements is another major reason for the performance of on-site treatment of hospital effluents in both developed and low- and middle-income developing countries.

2.1 Wastewater Treatment Trains Implemented in Hospitals

Typical treatment steps in a hospital wastewater treatment plant (HWWTP) include preliminary treatments such as clarification, followed by a secondary biological treatment and by a polishing treatment before its disposal in the sewer system or in the receiving natural environment.

2.1.1 Primary Treatment

Preliminary treatments are generally adopted with the aim of removing rough and coarse material from raw wastewater, thus protecting mechanical and electrical parts in the downstream treatment steps [13]. A septic tank was applied in three HWWTP locations: in Brazil, Nepal, and Ethiopia [24, 28, 33]. In a septic tank, by means of slowing down the wastewater flow, part of the solids settle to the bottom of the tank while the floatable solids (fats, oil, and greases) rise to the top. Up to 50% of the solids retained in the tank decompose; the rest accumulate as sludge at the tank bottom and need to be removed periodically by pumping the tank. Another example of primary treatment is chemical flocculation, the treatment applied in the dedicated full-scale HWWTP in Korea with the aim of removing suspended solids and colloids from wastewater that do not settle spontaneously [32]. In the recent study of Lien et al., both filtration and other physicochemical processes were applied as preliminary treatment before CAS in HWWTPs in two different hospitals in Vietnam [31].

2.1.2 Secondary Treatment

Conventional Sludge (CAS) and Membrane Biological Reactor (MBR) systems are the most used approaches for secondary treatment within the 23 studies covered in this chapter (Table 1). Traditionally, CAS processes have been the most representative technology at full-scale WWTPs, but such systems require a final settling step in order to separate the biological sludge from the effluent. In contrast, MBR combine the biological process with a membrane filtration step within one process unit, overcoming clarification and producing a high-quality effluent [38]. Moreover, passage through ultrafiltration membranes guarantees a better disinfection of the wastewater, thus reducing the risk of spread of pathogenic bacteria and of multidrug-resistant bacteria [13]. Finally, the absence of suspended solids in the MBR effluent makes it suitable for further tertiary treatment using advanced technologies such as NF and advanced oxidation processes (AOPs), since suspended solids can interfere with their removal performance [13]. Unfortunately, operating expenditures of MBR are still the main drawback that prevents their implementation, mainly due to aeration costs, membrane permeability loss, and hence need of regular membrane replacement [39]. Therefore, MBR systems applied for HWW treatment are investigated and implemented basically in European countries (seven studies) [1, 11, 18–22] and in China (three studies) [7, 29, 30] whereas nine studies in countries all over the world report about CAS treatments [1, 3, 23, 25–27, 31, 32, 35, 36], which are considered in general a more affordable treatment than MBR. The broad implementation of MBR systems for the treatment of hospital effluents in China is quite remarkable. Over 50 MBR plants were built for hospital wastewater treatment during the decade 2000s so that higher disinfection efficacy is achieved in MBR effluents at lower dose of disinfectant with less disinfection by-product (DBPs) formation [7]. Four case studies where MBR is applied to the treatment of hospital wastewaters were investigated by Liu et al. [7], five by Li et al. [30] and one by Wen et al. [29]. Concerning the type of membranes employed in MBR systems, ultrafiltration membranes were investigated in Italy [11], Netherlands [22], Denmark [18, 40] and at the Swiss, German, and Dutch units within the PILLS project [21], whereas microfiltration membranes were only used at the studies in Germany and China [19, 29]. Concerning the removal of PhACs in MBR systems, Verlicchi et al. reviewed the performance of several MBR systems for the treatment of hospital wastewater not only in full-scale but also pilot and lab scale treatments and observed that the aspects that greatly contributes to the removal of PhACs is the combination of higher biomass concentration in the aerated basin, the development of different bacterial species within the biomass, the smaller sludge flocks (that may enhance sorption on the surface of different contaminants), the higher SRTs, and the higher removal of suspended solids [13].

The performance of CAS treatment was assessed in nine studies for conventional parameters [26], PPCPs [23, 25, 31, 35], *Pseudomonas aeruginosa* [3, 36], enteric viruses and hepatitis A [35], and genotoxicity and mutagenicity [27]. In almost all cases, CAS treatment is followed by a disinfection step (chlorination). Only Sim et al. do not consider further treatment after CAS [32], whereas Lien et al. do not specify the type of disinfection step applied in their study [31]. Conventional parameters of seven WWTPs (CAS + chlorination) in Kerman Province (Iran) receiving hospital effluent in terms of removal of main conventional parameters was evaluated in the study by Mahvi et al. [26]. Disinfection is mandatory in Iran in case of disease outbreaks and in critical periods (in the summer and autumn due to reduced river water flow) [26]. Authors encountered that the most common malfunctions are due to operator inexperience at the WWTP and negligent WWTP management by the authorities. Chemical flocculation followed by a CAS process represents an efficient barrier for anthelmintic drugs (albendazole and flubendazole) considering that overall removal is in the range of 67–75% in a CAS-based treatment in Korea [32]. Finally, in the research by Kosma et al., removal efficiencies were provided for ten PhACs after CAS + chlorination (tertiary treatment) in Greece [23].

Other Biological Systems

Other biological systems applied for HWW treatment include ponds, constructed wetlands, and anaerobic treatment. Investigation was carried out at Hawassa University Referral Hospital (Ethiopia) to examine the suitability of a series of waste stabilization ponds (2 facultative ponds, 2 maturation ponds and 1 fish pond covering an area of about 3,000 m^2 with a total retention time of 43 days) for the treatment of hospital effluents [24]. The treatment was considered efficient in the removal of most of the general contaminant indicators, including total and fecal coliform (higher than 99.4%). However, final concentrations do not fulfill WHO recommendations for restricted and unrestricted irrigation, and the application of constructed wetlands was foreseen as a feasible option to comply with it. In fact, constructed wetlands (CW) are a feasible technology to be applied in developing countries for the treatment of wastewater. A two-stage CW after a septic tank is applied in Nepal to treat hospital effluent and consists in a horizontal subsurface flow bed (H-SSF bed) and a vertical subsurface flow bed (+V-SSF bed) planted with local reeds (*Phragmites karka*) [28]. Very good removal efficiencies were observed for TSS, BOD_5, COD, $N\text{-}NH_4$, as well as for total coliform (99.87–99.99%), *E. coli* (99.98–99.99%), and *Streptococcus* (99.3–99.99%). Finally, application of anaerobic treatment was also considered in some investigation carried out in Brazil on the removal of enteric viruses and hepatitis A [35] and in the removal of antibiotics and antibiotic resistance genes in China [30].

As regards to biological treatment of wastewater, special attention must be paid to evaluate the potential inhibition effect on the biological activities of pollutants such as PhACs, heavy metals, disinfectants, and detergents that occur at higher concentrations in HWW rather than in UWW; thus, the risk that they could negatively affect the degradation processes of microcontaminants has to be assessed [13]. Adequate pretreatment is extremely useful particularly in membrane bioreactor (MBR) configurations to avoid clogging of membranes and thus guarantee their continuous operation.

2.1.3 Tertiary Treatment

The tertiary treatment is the final cleaning process applied after secondary treatment to remove remaining residual organic matter, inorganic molecules, and remaining microorganisms. Tertiary treatment is necessary to remove in source points such as hospitals, those compounds that are not efficiently removed in conventional biological treatment, and also those particularly relevant from ecotoxicological point of view. In the dedicated treatments reviewed in this chapter, filtration through activated carbon both as powdered activated carbon (PAC) [21] and granulated activated carbon (GAC) [18, 22] as well as non-specified activated carbon [32] was the tertiary treatment more often used as well as ozone treatment [11, 18, 21, 22], followed by anaerobic filtration in three studies of Brazil [33–35] and sand filtration [25].

Tertiary treatment was applied either alone or in combination with other polishing treatment, including final disinfection with chlorine (up to nine studies) [3, 7, 23, 25–27, 30, 31, 35, 36] or UV irradiation [11, 18]. The disinfection of wastewater is particularly required if the wastewater is discharged into any water body used for recreational activities or as a source of drinking water (including aquifers) or if it is discharged into coastal waters close to shellfish habitats, especially if the dietary habits of local people include eating raw shellfish [10]. In these cases, disinfection will always be applied at the end of treatment train, just before discharge in the environment. Concerning PhACs, an overview of the global removals obtained with different strategies applied as tertiary treatment of hospital effluents is provided by Verlicchi et al.: being PAC, UV, and AOPs the ones achieving up to 90% removal of most PhACs groups considered, whereas PhACs removal percentages obtained through chlorination and coagulation ranged between 20–70% and 20–40%, respectively [13]. In the study carried out in a HWWTP in the Netherlands, none of the PhACs (32 different compounds) were detected in the effluent after tertiary treatment based on GAC + ozone [21]. Regarding the fate and use of treated HWW, in most of the 23 studies gathered together in Table 1, treated effluent was discharged into a natural water body, i.e., river streams, lake, or marine environment nearby, whereas only in four cases in the Netherlands, Greece, and Denmark treated hospital wastewater was discharged into the sewer system [18, 21–23] and further directed to the urban WWTP. Only in the case study of India the treated hospital wastewater was used as reclaimed water: treated wastewater was collected from the outlet of the treatment plant applied (CAS + chlorination) and further used for irrigating the gardens of the hospital [27].

2.2 *Water Quality Parameters*

Researchers can evaluate the performance of the HWW treatment on the basis of water quality parameters of the raw and treated water. The most common monitored parameters are COD, BOD_5, P, PO_4, total nitrogen, NH_3, NO_3^-, NO_2^-, TSS, TDS, Cl^-, total coliforms and fecal coliforms, as well as other microbial parameters. These are conventional parameters that provide the data necessary to assess if water meets minimal requirements for their disposal directly into the environment or in the sewer systems. However, other parameters have been attracting a lot of attention in the last years, e.g., the presence of emerging pollutants in hospital wastes. Among them, the occurrence and removal of pharmaceutical active compounds (PhACs) have been monitored in WWTPs worldwide in the last 20 years and hence also in HWWTP. PhACs are tackled in 9 out of the 23 studies listed in Table 1 [19–21, 23, 25, 30–34]. The high concentrations encountered in the HWW for many of these compounds as well as their potential environmental impact are the main reasons for their investigation in so many articles. As in the case of conventional WWTPs, treatments applied on-site in HWWTPs are not effective enough to degrade PhACs either, and thus WWTPs are considered the primary source of these compounds in the environment [6].

2.2.1 Antibiotics

Antibiotics are one of the PhACs classes with higher and increasing usage and consumption worldwide driven mainly by rising demand in low- and middle-income countries [41]. The most concerning effect of the antibiotics in the environment is the selective pressure they might exert in aquatic microbes, favoring the spread of antibiotic resistance genes (ARGs) and antibiotic resistance bacteria (ARB) [42, 43].

Hospital effluents have been reported to present a high load of antibiotics, among other pharmaceutical compounds, and thus discussion on the suitability of some source treatment has rose among the scientific community [11, 37, 44]. Antibiotics were studied specifically in three studies in on-site HWW treatment [30, 31, 34]. No apparent removal of the antibiotic ciprofloxacin (CIP) was observed after the treatment of HWW with a septic tank followed by an anaerobic filter in Brazil, with an average concentration in the treated effluent of 65 μg/L [34]. HWWTPs based on CAS treatment in Vietnam resulted in better removal values (21–91%) and thus lower concentrations of the studied antibiotics (metronidazole, sulfamethoxazole, trimethoprim, ceftazidime, ciprofloxacin, ofloxacin, and spiramycin). However, significant concentrations of these compounds were still present in the hospital effluents after the treatment (up to 53.3 μg/L of CIP) [31]. Ciprofloxacin was also found at high concentrations in various studies in hospital effluents [37, 44, 45]. These high levels might be related to its medical consumption, as these fluoroquinolones are frequently used in hospital practice to treat infections [46] and to its low biodegradability. CIP at a residue level as low as 25 μg/L can cause modification in bacterial strains and have genotoxic effects [47]. Removal efficiency of antibiotics in several HWWTPs based on MBR and CAS (all followed by a chlorination step) ranged from 72.4 to 79.3%, 36.0 to 52.2%, and 45.1 to 55.4% for tetracyclines (oxytetracycline, chlortetracycline, demeclocycline, and tetracycline), sulphonamides (sulfamethazine, sulfaonomethoxine pyridazine, and sulfadiazine), and quinolones (norfloxacin, enrofloxacin, ofloxacin, and ciprofloxacine), respectively [30]. In this case none of the antibiotics were above 1 μg/L in the treated effluent.

2.2.2 Antibiotic Resistance

As WWTPs are among the main sources of antibiotics' release into the environment, many studies have evaluated the fate of ARGs in WWTPs [48, 49]. As it happens with PhACs, conventional WWTPs are not designed to eliminate these pollutants, and therefore the efficiency of different nonconventional wastewater technologies in the removal and inactivation of ARGs has been studied by several authors in alternative WWTPs [50] and also in dedicated hospital WWTPs [3, 30, 36], the latest listed in Table 1.

Many authors even pointed out hospital wastewater treatment systems as contributors to the spread of antibiotic-resistant bacteria into the environment [5, 51]. Moreover, the diversity of gene cassettes is lower in hospital wastewater than in municipal wastewater, but the proportion of multiresistant bacteria (measured by integrons) in the bacterial community is higher in hospital wastewater than in municipal wastewater [21].

In developing countries, hospital effluents are often drained into municipal wastewater systems, and discharged into water bodies, frequently without any treatment aimed at reducing public health risks [3]. Therefore, the application of dedicated treatment for hospital wastewater would allow to minimize potential risk of hospital effluents on-site. Both the quantity of antibiotic-resistant integrons (representing the importance of antibiotic resistance in an environment independently of the quantity of bacteria) and the proportion of bacteria harboring a resistant integron in the same sample (the relative abundance) were investigated in two HWWTPs based on MBR followed by a specific tertiary treatment in the frame of PILLS project [21]. The efficiency of these advanced treatments to remove antibiotic-resistant integrons was between 1 and 5 log, mostly due to the elimination efficiency in the MBR (with ultrafiltration membranes of pore sizes of

0.03–0.04 μm) rather than the almost negligible effect of advanced treatment with ozone or activated carbon (tertiary treatment in the plant in Germany).

A study in China by Li et al. aimed to determine the contamination levels not only of ARGs but also of antibiotics and to analyze the relationships among them in hospital wastewater [30]. This study concluded that the relationships between the contamination level of ARGs and the concentrations of antibiotics should be further explored because the majority of ARGs showed weakly correlated levels of antibiotics. However, the study pointed out HWWTPs as a major reservoir for the evolution and dissemination of antibiotics and ARGs [30].

The diversity of *Pseudomonas aeruginosa* (a multidrug-resistant pathogen that has been suggested to be used as a microbial indicator of water biological quality) as well as its relatedness with β-lactams resistance mechanisms was investigated in the two studies performed in a HWWTP based on CAS followed by a chlorination step in Brazil [3, 36]. Authors concluded that treatment facilities for hospital wastewater can stimulate the increase of antimicrobial resistance bacteria and genes and thus calls for an improvement of water treatment to avoid the spreading of resistance genes in aquatic ecosystems.

In another study performed in Brazil, the contamination by viruses responsible for acute gastroenteritis and hepatitis derived from HWWTPs was confirmed as the systems investigated (UASB and three serial anaerobic filters and CAS system followed by a chlorination tank), which turned out not suitable for removal of the studied viruses present in the hospital wastewaters [35].

2.2.3 Toxic Effect

The analytical detection of pharmaceuticals or other micropollutants in concentrations lower than a few ng L^{-1} does not allow for a conclusion about possible toxic effects of single substances or about the effects of a mixture of compounds on the environment [21]. The toxic effects could involve endocrine disruption, genotoxicity, or antibiotic effects. Therefore, toxicological tests were used in several studies in Europe in order to assess the ecological risk of tested water [20, 21, 27].

A broad battery of ecotoxicity tests was applied for the evaluation of advanced wastewater treatments applied in one hospital in Germany and in the Netherlands such as in vitro screening tests for the assessment of specific effects (e.g., cytotoxicity or endocrine disrupting effects) and general toxicity to bacteria and algae as well as in vivo tests on organisms like snails, worms, water fleas, or fish. The biological treatment in the MBR decreased the toxic effects in raw hospital wastewater although MBR permeate was still toxic to some organisms like bacteria, algae, and snails. The treatment by activated carbon or ozone had in general decreasing effects on the toxicity. However, in some processes by ozonation, an increase of toxicity was observed presumably due to the formation of by-products [21]. The endocrine disturbing activity of the wastewater of a HWWTP (MBR + O3 + GAC) in the Netherlands was determined using four different parameters: ER, AR, GR, and PR-calux assay for substances able to bind to estrogen, androgen, glucocorticoid hormones, and progesterone receptors, respectively [22]. The various hormone disturbing parameters were no longer detectable in the treated wastewater filtrate [22]. ER calux as well as another estrogen activity test, lyticase yeast estrogen screen (LYES), and the H295R steroidogenesis assay (H295R) was applied for the monitoring of HWW treated by an on-site MBR system followed by ozone treatment in Germany [20]. Overall, treatment of sewage by use of MBR successfully reduced estrogenicity of hospital effluents as well as substances that are able to alter sex steroid production. However, although ozonation was an efficient method (based on the tests applied) to remove most of estrogenic activity, further investigation should be undergone regarding the formation of endocrine active metabolites [20].

Monitoring of the genotoxic and mutagenic potential of the effluent from a hospital in India were carried out using a *Salmonella* fluctuation assay and the SOS chromotest. Untreated raw HWW revealed their highly genotoxic nature, whereas treated WW through CAS treatment followed by chlorination did not exhibit that type of toxicity [27].

3 Conclusions and Future Prospects

Hospital wastewater can represent a chemical and biological risk for environmental and public health due to the presence of several types of hazardous substances. Certain contaminants are in fact present in much higher amounts in hospitals than in municipal effluents. On-site HWWTPs offer the opportunity to eliminate high amounts of these specific contaminants before they can be released and impact the environment. While the need to implement such dedicated treatments in hospital is still under discussion, several initiatives and case studies in full-scale HWWTPs have been applied all over the world and were reviewed in this chapter.

The most suitable approach for hospital wastewater would consist of a pretreatment, a main biological treatment, an advanced treatment, and a posttreatment. In Asian countries, a conventional secondary biological treatment (CAS) followed by chlorination was considered an adequate treatment but only based on the analysis of conventional contaminants and without considering the presence of micropollutants or ecotoxicological values. In a broad set of studies in Europe and China, MBR technology was raised as an appropriate treatment for hospital wastewater. However, in both cases (CAS and MBR), biological treatment of hospital wastewater does not provide a sufficient elimination of some compounds such as pharmaceuticals and some pathogenic microbes. Only additional advanced steps like ozonation, activated carbon, or AOPs will enable a better elimination of these compounds.

Other critical factors need to be investigated when evaluating the performance of dedicated full-scale WWTPs. For instance, the evaluation and monitoring of wastewater losses between entry points (sinks, toilets, drains) and the on-site treatment plant or tank or discharge point into a municipal sewage [10]. Decoupling of the rainwater drainage system can also led to a more efficient treatment of the hospital wastewater [1]. On the other hand, sewer overflows from municipal sewer systems may lead to discharge of hospital wastewater into the receiving waters, a potential risk of spreading resistant bacteria and pathogens as well as other chemical contaminants [21]. To this respect, antibiotic resistance is a topic of increasing environmental concern and hospitals, hospital effluents, and even HWWTPs are under the spotlight regarding their critical role in the spread of antibiotic resistance in the environment.

Finally, in accordance with the environmental relevance of the emerging pollutants, and based on the studies performed in the last years, some of these emerging pollutants are currently being considered for environmental legislation in different countries. In the case of the European Union, the anti-inflammatory drug diclofenac and three macrolides antibiotics (erythromycin, clarithromycin, and azythromycin) have been included in the so called “watch list” of priority substances under the Water Framework Directive (WFD) for the “specific purpose of facilitating the determination of appropriate measures to address the risk posed by these substances” [52]. In United States, the Environmental Protection Agency (EPA) has included the antibiotic erythromycin and five synthetic hormones to a list of contaminants that must be controlled, the Drinking Water Contaminant Candidate List [53]. Finally, in 2008 the Global Water Research Coalition (GWRC) published a report in which a large number of PhACs were classified in several classes: high, medium, and low priority compounds. This report identifies compounds that are most likely found in water supplies and that may have significant impacts on human and environmental health [54]. Future regulation of these compounds and the establishment of specific limit values in water would definitely affect the management of hospital effluents as they are significant sources of many of these compounds. In this scenario, the increase in the number of dedicated full-scale HWWTPs can only be foreseen, and therefore further efforts need to be devoted to research in the field.

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