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Hospital wastewater treatment scenario around the globe

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15.1 Introduction

Hospitals have an important role in the well-being of mankind and other medical research advancements. Different units/services of hospitals require large volume of water according to the activities taking place within the hospitals and generates large amount of wastewater [1]. Quantity as well characteristics of hospital wastewater (HWW) is affected by size (number and type of wards/units), and services provided (kitchen, laundry, and air conditioning), management policies and awareness of the institution [2–4]. A hospital in developed country generates 400–1200 L wastewater per bed per day whereas for developing countries the value is 200–400 L/capita/day as compared to 100–400 L/capita/day of domestic wastewater generation [5–9].

In general, characteristics of wastewater generated from hospitals are similar to the domestic wastewater, but a proportion of the HWW contains toxic/nonbiodegradable/infectious pollutants [3,10–12]. The hospital effluents contain a large variety of substances used for medical, laboratories, research purposes, and also include excreta from patients [2,3,13,14]. These wastes include drugs and their metabolites such as antibiotics, lipid regulators, analgesics, antidepressants, antiepileptics, antineoplastic, antipyretics, antiphlogistic, antirheumatics, estrogens, organic matters, radionuclides, solvents, metals, disinfectants, cytostatic agents, anesthetics and sterilization products, specific detergents for endoscopes and other instruments, radioactive markers, and iodinated contrast media [4,14–18]. Metals present as preservatives in diagnostic agents such as platinum, mercury, rare earth elements (gadolinium, indium, osmium), and iodinated X-ray contrast media [19–22].

These insoluble/soluble organic/inorganic pollutants have adverse toxic effect to humans as well as aquatic animals even at very low concentration and termed as biological active substances [18,23,24]. These effluents also carry pathogenic microorganisms such as viruses, bacteria, fungi, protozoans, and helminths which induces pressure of rapid adaptation to

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these fluctuating conditions through genome rearrangement in innate microorganism [25]. This exchange of genes develops a resistance trait in pathogens [10,15,25].

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 [4,17,26,27]. According to the diversity of contaminants, it has been demonstrated that the intrinsic toxicity of the hospital effluents can be 5–15 times greater than an urban effluent as well as the potential inhibition of the activated sludge of wastewater treatment plants [1,14,28].

Therefore dealing with HWW and healthcare waste in a way that can minimize potential risks for local populations is one of the greatest challenges faced by healthcare facilities. A growing body of evidence indicates that HWW treatment systems contribute to spread antibiotic resistant bacteria into the environment [10,27].

Mobilization and return of the contaminants to the food chain or in drinking water increases the possibility of exposure of organisms to hazardous substances imparting greater risks to the environment in the long run [29]. Table 15–1 depicts the comparison between average range of parameters which hospital effluents can bring to the municipal sewage system such as biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), total kjeldahl nitrogen, total phosphorus (TP), and coliforms.

The facilities discharging waters directly to municipal sewer system are called indirect dischargers whereas those that directly discharge to rivers are called direct dischargers. Majority of hospitals are indirect dischargers [26,29,45,46]. These wastes if not handled properly could be dangerous to the ecological balance and public health and may lead to outbreaks of communicable diseases, diarrhea epidemics, water contamination, and radioactive pollution [3,9,11,13,24,47]. Even the urine and feces of patients from specific wards such as oncology contains higher amounts of antibiotics, cytotoxics, their metabolites, and X-ray contrast media, and contributes around 50%–80% of total toxic discharge concentration to the

Table 15–1 Comparison of average range of parameters of HWWs and MWWs.

Parameters	HWW[a]	MWW[b]	References[a]
BOD_5 (mg/L)	200–300	150–400	[10,19,20,26,30–32]
COD (mg/L)	120–500	50–170	
TSS (mg/L)	150–160	50–60	
Total N (mg/L)	5–80	20–70	[7,9,14,17]
Total P (mg/L)	0.2–13	4–10	
Chlorides (mg/L)	65–360	30–90	
Total surfactant (mg/L)	3–7.2	4–8	
E. coli (MPN/100 mL)	$10^3 - 10^6$	$10^6 - 10^7$	[5,10,12,21,33–37]
Fecal coliform (MPN/100 mL)	$10^3 - 10^7$	$10^6 - 10^8$	
Total coliform (MPN/100 mL)	$10^5 - 10^8$	$10^7 - 10^{10}$	

[a]Some of the common references are cited here: [1,4,6,23,26,38–43].
[b]Some of the common references are cited here: [44].

HWWs [2,3,5,9,13,18,44]. Thus appropriate planning and implementation of hazardous liquid waste management by sewer authority can reduce negative impacts of HWW [2,5,48].

15.1.1 Characterization of hospital wastewater

WHO has characterized these hospital wastes in following ways in World Health Organization's (WHO's) health and environment lexicon [29,45–47].

- **i.** Blackwater (sewage) contains mainly fecal matter and urine.
- **ii.** Greywater (sullage) contains residues from washing, bathing, laboratory processes, laundry, and other technical processes such as cooling water or the rinsing of X-ray films, potentially loaded with a genotoxic or cytotoxic agent.
- **iii.** Storm water contains rainfall collected from roofs, grounds, yards and paved surfaces, water used for irrigating hospital grounds, toilet flushing, and other general washing purposes which may be lost to drains and watercourses and as groundwater recharge.

Further, discharges from kitchens, laundries, and toilets of normal wards are termed as domestic discharge. Wastewater generated by research and laboratory activities, disinfectants, detergents, drug residues, infectious excreta, radioelements, and other chemicals such as acids, alkalis, solvents, benzene, hydrocarbons, and colorants are called specific discharges [47].

HWW could be a major source of toxic elements such as gadolinium (Gd), mercury, platinum, and other heavy metals such as Cd, Cu, Fe, Ni, Pb, and Zn [17,22,49,50]. HWWs coming from dental hospitals carry dental amalgam and medical devices residue discharges mercury, silver, tin, copper, and zinc to water bodies [9,47].

15.1.2 Guidelines around the globe

The effective review of regulations and specific norms or guidelines at international level regarding handling and management of HWW has revealed a great difficulty in discovering. Globally, the only guiding regulation "Safe Management of Wastes from Health-Care Activities" to manage HWW was made available by WHO in 1999 [29], later it was updated in 2013 [45].

According to safe management of wastes from health care by WHO direct discharge of hazardous liquids and chemical wastes (photochemicals, aldehydes, colorants, and pharmaceuticals) to sewer is strictly prohibited. Separate collection and pretreatment are required for wastewater from medical laboratories. The pretreatment could involve filtering of sediments, acid–base neutralization, or autoclaving. Nonhazardous chemicals such as syrups, vitamins, or eye drops can be discharged to the sewer without pretreatment whereas radioactive wastewater should be collected and stored separately until their radioactivity level have decreased to safe limit [47]. Table 15–2 presents the names of four major guidelines focusing on the management of HWWs globally. (Table 15–3)

Table 15–2 Guidelines on the management of hospital wastewaters.

Guidelines	Source	Year	References
Effluent Guidelines and Standards (CFR 40)(NPDES) (National Pollutant Discharge Elimination System)	EPA	2015	[47]
Safe management of wastes from healthcare activities	WHO	2013	[46]
Release of patients after radionuclide therapy	IAEA	2005	[51]
Release of patients after therapy with unsealed radionuclide	ICRP	2009	[52]

Table 15–3 Country wise laws, permissible parameters and treatment options of HWW.

Country	Law	Permissible parameters of HWW	Treatment option	Reference
Developing countries				
China	National Standard of People's Republic of China	pH 6–9 SS [mg/L] 0–400 BOD_5 [mg/L] 0–300 COD [mg/L] 0–500 Fluoride [mg/L] $\leq$ 20 Phosphorus [mg/L] $\leq$ 0.3 AOX (as Cl) [mg/L] $\leq$ 8 Fecal coliform [individual/L] 1000–5000	Specific Treatment	[53]
India	The Biomedical Waste Management and Handling Rules 1998, 2013	pH 5.5–9.0 BOD_5 [mg/L] < 350 COD [mg/L] < 250 SS [mg/L] < 600 Oil and grease [mg/L] $\leq$ 20 Ammonical Nitrogen [mg/L] $\leq$ 50	Direct disposal/cotreatment/specific treatment	[38]
Africa	As per Effluent Guidelines and Standards USEPA	–	Cotreatment	[47]
Developed countries				
Europe	European Directives concerning urban wastewater treatment	–	Specific treatment	[54]
USA	Effluent Guidelines and Standards	pH 6.0–9.0 BOD_5 [kg/1000 occupied bed] 33.6 TSS [kg/1000 occupied bed] 33.8	Specific treatment	[47]
Australia	Australian Public Health (Wastewater) Regulations 2013	–	Cotreatment	[55]

15.2 Global scenario of hospital wastewater treatment

A working group consists WHO personnel, medical specialists, hospital engineers, and administrators from 19 countries concluded that treatment of HWW involves awareness, segregation, and pretreatment of waste [46,56]. Most of the countries across the globe did not have a proper distinction between wastewater originating from hospitals and urban areas. Potential hazardous loads of these effluents are generally discharged directly into the public sewage network without any prior identification of source of toxicity [25]. These regulations contradict their implementation status. For example, WHO [46] and European Directives [54,57] have listed mercury in list I of dangerous substances with the allowable limit of up to 5% in discharge from effluent of hospital wastewater treatment plants (HWWTPs). But in the United Kingdom and Europe itself contribute more than 50% of total mercury, silver, tin, copper, and zinc from dental amalgams coming from hospitals [14,15,58].

In most of the countries including Denmark, Greece, Italy, Iran, Taiwan, Korea, Ethiopia, Saudi Arabia, India, Nepal, and Vietnam, very few studies were carried out for treatment of HWW [10,33,56,59,60]. The countries like China and Japan experienced high rates of epidemics of enteric and cancerous diseases therefore adopted specific on-site pretreatment of HWWs before discharging into the municipal sewerage system to avoid/prevent the outbreaks due to pathogens [10,16,18,27]. European countries adopted treatments only due to the awareness about the risk possessed by HWW [1,9,28,34,44,45,48,57,61–63].

15.3 Status of hospital wastewater management in developed countries

15.3.1 The United State

In the United States, the most important law governing wastewater discharge into surface water bodies is the Clean Water Act (1972) and its updated version in 2002 [45]. On the basis of the said act-specific regulations and discharge permits for treatment/handling of HWW pollution were published and implemented. It is highly recommended that management should employ best control technology before every discharge of HWWs to the surface water or municipal wastewater treatment plants or publicly owned treatment works must comply with effluent discharge guidelines of the country as per the discharge norms of the local authority [26,35,36,47,64,65]. United State Environmental Protection Agency (USEPA) has formed a list of contaminants of toxic and harmful nature which include an antibiotic “erythromycin” and five synthetic hormones [47]. United States Commercial Service has instructed its companies to transfer membrane biofilm reactor (MBR) technology to Chinese hospitals after the outbreak of severe acute respiratory syndrome (SARS) because MBR has higher removal of bacteria and viruses [4,56,66,67].

The fate of psychoactive and antihypertensive drugs in WWTPs of New York State, NY was studied by Subedi and Kannan [68]. Treatment plants WWTP-1 and WWTP-2 had a treatment capacity of 2.5 and 35 million gallons/day, respectively. In both of the WWTPs, the wastewater treatment begins with the mechanical screening of solid particles followed by primary clarification which reduces approximately 40%–60% BOD of the wastewater. The wastewater then directed for the biological treatment which utilizes conventional activated sludge process for removal of organic contaminant. The secondary clarifier, after the activated sludge process allows the settling of sludge. The wastewater is then disinfected using chlorine and treated effluent was discharged into environment [68]. Subedi and Kannan [68] analyzed the fate of 27 psychoactive drugs, and all the targeted pharmaceuticals were detected in wastewater and sludge of WWTPs. The concentration of psychoactive pharmaceuticals in wastewater and sludge was ranged from 0.98 to 1220 and 0.26 to 1490 ng/L, respectively. The removal efficiency of pharmaceutical in WWTPs ranged from 0.3% to 87% after the final treatment. However, the negative removal of seven pharmaceuticals, namely carbamazepine, lorazepam, norsertraline, propranolol, clopidogrel, carboxylic acid, and 2-(diphenylmethoxy) acetic acid was observed. This negative removal could be due to the microbial transformation of conjugated drug into their parent compound. Both of the WWTPs on an average contribute approximately 0.01–316 mg/day/1000 inhabitant load of psychoactive drugs into the environment [68].

15.3.2 United Kingdom

In the United Kingdom, the extent of presence and distribution of pharmaceutical waste in HWW has less evident consequences as compared with other countries despite of large volume production, consumption, and wastage of pharmaceutical every year. The country has more than 100 tons/year consumption of top 25 pharmaceutical compounds in year 2000 [10,46,54,62]. Discarded pharmaceuticals in the United Kingdom were defined by the Controlled Waste Regulations (1992) [57]. Clinical waste is also monitored by the Special Waste Regulations (1996) [46]. According to the said legislation, landfill sites were designed to accommodate hazardous sludge. HWW sludge when dumped in landfills it undergoes biologic degradation processes but increases a chance of percolation of leachate to the groundwater [61].

15.3.3 Europe

Before 1990, no specific guideline was available for managing HWW, in European countries as they assume hospital discharge to be comparable to that of municipal wastewater [54]. So the member states of Europe follows their own laws and regulations to characterize and treat HWW. Thus European Union Water Framework Directive (EU-WFD) in 1991 has demanded a preauthorization on discharge of industrial waste into domestic wastewater collection system for improving and protecting the quality of wastewater releasing into watersheds [57].

Approximately, on every 10,000 populations, there are around 2.6 hospitals, with approximately 530 beds per hospital (the lowest in Spain around 320 to highest in Germany around 800) are available in Europe. HWW discharge in Europe is approximately 0.3–0.7 m^3/bed/day [1,3,4] and antibiotics consumption is approximately 10,000 tons/year, a major portion of which ultimately ends up in wastewater streams via urine and faces [22,23,60,69].

Nowadays in Europe, wastes are segregated at the point of generation and toxic items are incinerated at source. According to European pills project reports (2010–12), the removal of pharmaceutical compounds from HWW can be done employing MBR along with various sets of removal technologies [37]. Most common of them are MBR with powdered activated carbon (Switzerland), MBR with ozone/UV/RO/H_2O_2 treatment (Luxembourg), and MBR with ozone treatment and granular-activated carbon (GAC) (Netherlands) [4,44,50].

European Union has formed a "watch list" of antiinflammatory drug, diclofenac, and three antibiotics (erythromycin, clarithromycin, and azythromycin) present in HWW to facilitate and take appropriate measure to solve the issue of risk posed by these contaminants [15,38,60,70]. But currently none of these rules are in action as per Herlev Hospital, Copenhagen, Denmark. The WWTP of this hospital employs a modular system which involves biological purification, filtration, and a final "polishing" with activated carbon and ozone [38,62].

In Denmark, the first full scale wastewater treatment plant (WWTP) for treatment of HWW was constructed in 2013 [38]. The hospital WWTP was designed to treat wastewater originated from Herlev hospital which discharged approximately 150,000 m^3/year of wastewater and expected to discharge 200,000 m^3 of wastewater by 2020 [15]. The various department of Herlev hospital such as oncology department, radiology department, cardiology department, cancer treatment facility, and other sections of hospital utilizes around 850 pharmaceutical active substances. The hospital was considered as major point source which discharge approximately 700 kg/year of hazardous pharmaceuticals in marine environment. The raw HWW causes death of crustacean and zebra fish within 96 h of exposure and also found to contain high concentration of antibiotic-resistance bacteria (ARB) and norovirus (1.7×10^5) [15].

The WWTP having capacity to treat 500 m^3/day of wastewater was constructed in 2013 to treat HWW. The Herlev hospital WWTP consists of two biological tanks for secondary treatment followed by adsorption with GAC, ozonation, and UV radiation. Fig. 15–1 shows the WWTP process of Harlev hospital. The primary treatment involves the screening of the wastewater to remove solid particles. The screened solid particles were then incinerated at 850°C–1200°C in waste incinerated tank. After the screening process, the wastewater was pumped to biological process tank in which intermittent aeration and coagulant (aluminum) were provided for simultaneous removal of nitrogen and phosphorus. The wastewater was then pumped to membrane bioreactor which consists of a ceramic membrane having a pore size 0.2 μm. The sludge retention time of the biological process was approximately 30 days with TSS concentration 5000 kg. The permeate collected after membrane filtration was pumped for ozonation in which 3.4 mg O_3/L of wastewater was provided for maximum removal of pharmaceuticals. Following the ozonation process, the treated wastewater was then treated with GAC. The GAC was configured with three filter columns in series. After the GAC treatment, the water was polished using UV radiation. The UV installation consists of one UV lamp of 220 W. The wastewater was then discharge to public sewer. The sludge generated during biological process ($\sim$165 kg/day) was dewatered, dried, and then passed to incineration tank [15].

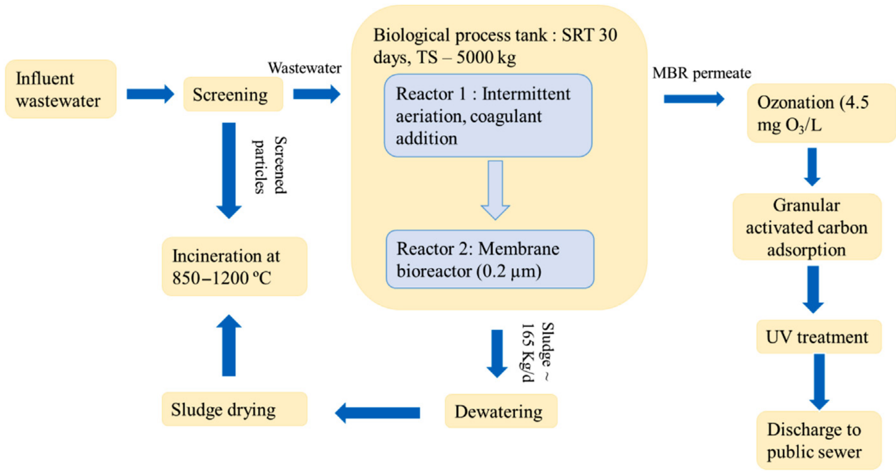

FIGURE 15–1 Flow diagram of Herlev hospital wastewater treatment plant, Herlev, Denmark.

Biobooster [14] also analyzed 122 pharmaceuticals compound divided into 16 indicator group in influent, MBR permeate, and final effluent of Herlev hospital WWTP along with other organic contaminants. The initial concentration ranges of COD, total nitrogen (TN), and TP were 400–1100, 40–100, and 10–20 mg/L, respectively. The biological process of WWTP was able to remove 97% of COD, and the after tertiary treatment (ozonation, GAC, and UV) the residual concentration of COD in treated water ranged from 5 to 10 mg/L. Furthermore, the biological process accounts for maximum removal of TN and TP, that is, 85% and 95%, respectively, from wastewater; however, the tertiary treatment did not affect the removal of TP and TN at greater extent. In pharmaceutical analysis, the concentration contrast media (Iomeprol) was highest, that is, 2.9 mg/L, followed by paracetamol (0.35 mg/L) in raw HWW. The MBR was found to removal approximately 95% of analyzed pharmaceuticals (122 drugs and metabolite); however, the contrast media was not degraded during biological treatment. The polishing treatment of MBR permeate, that is, ozone, GAC, and UV was found to remove 99% of all pharmaceuticals, and none of the pharmaceutical concentration was above predicated no effect concentration of freshwater [14]. The ecotoxicology test on treated water had no negative effect on *Daphnia magna* and embryo of zebra fish [14].

The performance of Bellecombe WWTP, France, having separate basin for treatment of HWW was evaluated [35]. The HWW originate from CHAL hospital, situated in Contamine sur Arve, France was pumped to Bellecombe WWTP via separate sewer system. The Bellcombe WWTP has three basins in which two basins collect and treat urban wastewater (UWW) while the third basins having a capacity of 1280 m^3 treats HWW. Bellcombe WWTP has aerated grit chamber and screen bar for primary treatment of wastewater. All the three basins utilize activated sludge process with sequential aerobic and anoxic condition for removal of contaminants. The treated water is then disinfected using chlorine and discharged into Arve river [35]. Wiest et al. [35] compared the characteristics of influent and effluent of UWW and HWW which were treated in Bellcombe WWTP separately. The study reveals high concentration of organic carbon, paracetamol, ketoprofen, antibiotics, and gadolinium in HWW compared with UWW.

The removal efficiency of HWW treatment basin was higher compared with UWW. For instance, the removal of diclofenac and propranolol in HWW line was 77% and 87%, respectively, while the UWW line was able to remove only 30% of diclofenac and 70% of propranolol. In spite of these difference, both of the treatment lines were not able to remove carbamazepine, and a negative removal of carbamazepine was observed. Excluding carbamazepine, the overall pharmaceutical removal efficiency of HWW and UWW treatment lines range from 75% to 100% and 30% to 100%, respectively. Even though certain antibiotics (such as vancomycin and ciprofloxacin) that are frequent in HWW and not regularly detected in UWW, the pharmaceutical load of UWW to environment was higher. The UWW effluent discharge was 37 times more than the HWW effluent discharge, which justify the higher contribution of pharmaceutical from UWW to the environment. Chonova et al. [37] studied the effect of separate treatment of UWW and HWW on microbial community of Bellcombe WWTP using denaturing gradient gel electrophoresis technique. The 34% operational taxonomic unit (OTU) was shared by both of the treatment basins (UWW and HWW). However, 25% OTU was present only on HWW line and 41% OTU was exhibit only in UWW treatment basins [71]. In spite of similar treatment techniques of both the basins (UWW and HWW), the difference in the bacterial community structure could be due to the variation in wastewater characteristics. It was expected that the high concentration of pharmaceuticals and nutrient in HWW was key shaping factor of the microbial community [70].

15.3.4 Australia

In Australia, wastewater generation from hospitals is approximately 750 L/bed/day. HWW produced there is directly discharged in the municipal sewer for the treatment in MWWTP along with municipal wastewater. This practice is termed as cotreatment [6,38]. However, Australian policies for HWWT suggest on-site treatment to ensure the protection of environment from the possible contaminants diffusing into the natural ecosystem [54].

For 60 years, Australia is the largest consumer of pharmaceuticals and contributes significant quantity of pharmaceutical residues in the environment, even though, the parameters related to pharmaceuticals have not been added to guidelines for drinking water quality. Among top 10 most used antibiotics in Australia, 9 were identified in WWTP influent [46].

Literature demonstrated the presence of certain clonal groups of *E. coli* in both HWW and STP influents resistant to beta-lactam antibiotics [25,71]. Generally, the strains found in HWW are more resistant than STP strains that represent high usage of antibiotics in hospitals. According to the Joint Expert Advisory Committee report on Antibiotic Resistance during 1992 to 1997, the average use of beta-lactam inhibitors, carbapenems, and cephalosporin's is approximately 40,000 kg/annum [72].

15.4 Status of hospital wastewater management in developing countries

15.4.1 India

In India, wastewater coming from hospitals is generally discharged to municipal sewer without any treatment [13]. These direct dischargers when mixed with sewage of a common WWTPs impart potential risk to the environment because these WWTPs are not designed according to contaminants of HWWs [61]. In India, this common practice has led to almost total extinction of some white-romped sharks and genetic conversion of male fish to female due to excessive concentration of pain killers and contraceptive hormones in aquatic regions [12].

India has conceded the Biomedical Waste (Management and Handling) Rules, 1998 [72] and revised version in 2016 [73]. The said rule outlines the methods to collect, transport, and dispose hospital wastes and wastewater. Despite this legislation, most of the medical wastes in India are dumped in the open and collected with the general waste. Unfortunately, the Indian press often reports cases in which hospitals are shut down or are not following regulations for waste disposal [5,74–77].

According to World Bank HWW management practices in India differs from state to state. For example, in Punjab and Karnataka, HWW is disinfected on-site and then discharged to sewer drains as per "Bio Medical Waste (Management and Handling) Rules, 1998" whereas in Maharashtra HWW is stored in leak proof buckets, neutralized and then sent to drains [78]. Researchers have also reported that the sediments of most of the river stream receiving HWWs directly without treatment are heavily contaminated with heavy metals [11].

Now attention has been given to on-site treatment of HWWs as it can solve the problem of dilution and spread of pathogens from its discharge to municipal sewer system. This on-site treatment may include sedimentation and/or coagulation, filtration followed by disinfection by $FeCl_3$/UV and conventional digestion of the settled solids before discharging to MWWTPs [14]. The sewage sludge contains high concentrations of helminthes and other pathogens which need to be handled carefully [39,61,79]. A few studies have discussed the presence and harmful of helminths egg and other biologically active pathogens on mankind.

India has a turnover of USD45 billion/year and stands among the top 5 of 250–300 pharmaceutical companies around world. It can be assumed that, every third pill taken in the world is manufactured in India. Acknowledging this high rate of manufacture, some reports have also stated that 10%–90% of the consumed medicine gets excreted from the human body in their parent form, while the rest gets metabolized and/or conjugated [40]. When these raw and conjugated metabolites reach the MWTPs and finally to the groundwater, rivers, lakes, oceans, and soil can be very harmful to certain aquatic organisms and form ARBs and antibiotic-resistance genes (ARGs) [14,61,74].

Despite the high rates of production of harmful pathogens, the proper sewage treatment plants (STPs) are falling short across the country and most of the researches countrywide are mainly focused on parent drugs. Therefore it becomes necessary to lower the concentration ranges of discharge metabolites into the environment.

15.4.2 China

According to China Health Statistics Annuals (2008), the total number of hospitals was 14,377 in 1990 and 19,712 in 2008, thereby increasing the amount of HWWs up to 1.29×10^6 m^3/day which is 1% of total MSWW [53,66]. There was not any special guideline to treat HWW as separate waste, before July 2005. The pathogenic outbreaks of diseases through sewage resulted in SARS in 2003 have forced authorities to take specific safety measures rapidly to the STPs receiving HWWS to protect the future [4,7,66,80].

Therefore, in 2005, a document outlining the handling of HWW was published entitled as "Discharge standard of water pollution for medical organization." China has more than 25,000 tons of antibiotic usage annually as compared with global usage per year as 200,000 tons which makes it the one among the largest contributors. But very few studies have reported the existence and variety of antibiotics released from large population areas to river in China [53].

To search for a technology for enhancement of public health and the environment and comply with the more and more stringent regulations, a cost-effective method named as MBR is being introduced for HWW treatment. More than 50 commercial MBR plants for HWW treatment are already being implanted with capacity ranging from 20 to 2000 m^3/d in China [66]. The operation and maintenance cost along with initial investment costs 0.43–0.163 €/m^3 [38,71,72]. Liu et al. [66] compared the treatment efficiency of various HWWTPs of China employing MBR process followed by chlorination step for disinfection. The study discussed the removal of COD, BOD, NH_3, TSS, turbidity, bacteria, and fecal coliforms; however, the removal of pharmaceutical residues was not considered in the study. The treatment of HWW using MBR reduces the concentration and reaction time of hypochlorite during disinfection treatment process. The study concluded the MBR-treated effluent followed by chlorine disinfection process meets the Chinese wastewater discharge guidelines [66]. Yuan et al. [40] investigated the occurrences and treatment efficiency of two wastewater treatment plant (WWTP-P1 and WWTP-P2) of psychiatric hospital of China. The WWTP of psychiatric hospitals involves primary treatment for removal of solid particles followed by conventional activated sludge process as secondary effluent [40]. The study investigated the occurrences and fate of psychiatric pharmaceuticals grouped in three classes in influent and effluent of WWTPs, namely antidepressants (chlorimipramine, citalopram, fluoxetine, sertraline, and fluvoxamine), antischizophrenia (olanzapine, clozapine, chlorpromazine, risperidone, sulpiride, quetiapine, ziprasidone, aripiprazole, and perphenazine), and sedative hypnotics and anxiolytics pharmaceuticals (lorazepam, oxazepam, trihexyphenidyl, and carbamazepine). The average concentration of clozapine was highest among other pharmaceuticals in influent of both of the WWTP and accounts for 5553 ± 443.5 and $12{,}783 \pm 564$ ng/L in WWTP-P1 and WWTP-P2, respectively. Some pharmaceuticals, that is, alprazolam, lorazepam, zaleplon, chlorimipramine, and fluoxetine was detected only in influent and effluent of WWTP-P2 in concentration ranging from 12 to 294 ng/L. The comparison of influent and effluent of both of the WWTP (WWTP-P1 and WWTP-P2) showed that the secondary treatment of HWW was effective in removal of majority of psychiatric pharmaceuticals [aripiprazole (64%–70%), olanzapine (93%–98%), quetiapine (>73%), and risperidone (72%–95%] [40]. In spite of high removal of psychiatric pharmaceuticals in WWTPs, the residual concentration of pharmaceuticals in treated effluent was higher compared to the influent of MWWTP [40]. Thus advanced secondary treatment (such as MBR or sequence batch reactor) or tertiary treatment (such as coupled process advance oxidation process or disinfection) was required for neutralization of pharmaceutical compounds.

A hospital in Tianjin (China) has employed MBR along with biological oxidation followed by disinfection at lower doses with less disinfection by-product formation. Effluent thus produced met the Chinese Discharge Standard of Water Pollution for Medical Organization, so china adopted on-site–specific treatment methods for HWWs [80]. In Kunming City, of 45 hospitals, 36 were equipped with disinfection equipments; and in Wuhan City, 46 of 50 hospitals have their own WWTP but only about 50% of them have the effluent quality in accordance with the national discharge standards [66].

15.4.3 Africa

According to United Nations Development Program's [80], Africa lacked guidelines for the management of medical waste. Thus, the HWW are directly discharged into the municipal sewer system where it was co-treated with urban wastewater [53]. This process is mainly termed as cotreatment. This practice is common in Australia, Iran, Egypt, India, and Japan [2,12,16,46]. Ghana, Lesotho, and Eritread onto follow any guideline for HWW treatment and disposal, whereas Nigeria, Gambia, and Kenya are among one of the signatories of Stockholm convention 2009 [4,57,80].

South Africa usually adopts the USEPA regulations for treatment of Class A sludge coming from hospitals, which is unrestrictedly used in agriculture without any further monitoring. Sludge thus produced undergoes further treatment (air-drying, composting, and long-term storage) to meet the national standards of effluent discharge [6,80].

15.5 Other countries

15.5.1 Saudi Arabia

The full-scale dedicated facility of onsite treatment of HWW in Saudi Arabia was studied to investigate the efficiency of treatment process for removal of micropollutant and ARGs [81]. Qarni et al. [81] investigated and compare the removal of pharmaceuticals compound from two hospital having onsite WWTP (WWTP-H1 and WWTP-H2). The WWTP-H1 treats approximately 330,000 m^3 of wastewater annually and involves conventional activated sludge process followed by chlorination treatment for HWW treatment. In the WWTP-H2 which treats 227,000 m^3/year of HWW utilizes activated sludge tank operated in anoxic and oxic zone for efficient removal of micropollutant. The wastewater characteristics of both the hospitals were similar having COD concentration of 376 and 336 mg/L and NH^{4+} concentration of 22.3 and 19.0 mg/L in hospital 1 and hospital 2, respectively [80]. Apart from organic contaminant, the concentration of pharmaceutical residues was also similar in both of hospitals, for instance, analgesic pharmaceutical paracetamol concentration was 12.4 and 12.3 μg/L in influent of H1 and H2, respectively. The removal efficiency of both of the WWTP (H1 and H2) was >99% for caffeine, ciprofloxacin, sulfamethoxazole, and paracetamol. In comparison with other studies, the high removal of carbamazepine (>86%), atenolol (89%), and lidocaine (64%) was observed in both of the WWTPs [81]. The high removal of pharmaceuticals in these WWTPs could be due to the tropical climate which enhanced the microbial activity and exposure to sunlight facilitated the photodegradation of pharmaceutical compounds. The investigation on the presence of ARB, ARGs, and integrase gene in effluent of WWTP of H1 and H2 was conducted by Timraz et al. [27]. WWTPs were found to effectively remove ARBs from effluent; however, a high concentration of ARGs specifically *sul1* and *int1* up to 10^5 per copy number was observed in effluent of WWTPs. The author also reported a significant shift in microbial community while onsite treatment of HWW [27].

15.5.2 Brazil

Several research investigations provide the details of HWW treatment scenario of Brazil in which a separate or on-site treatment of HWW was performed; however, none of them provided the concentration and removal of pharmaceuticals in HWW [25]. Santoro et al. [25] studied the antibiotic resistance profile of *Pseudomonas aeruginosa* in WWTP of hospital situated in Rio de Janerio, Brazil. The hospital WWTP treat 220 m^3/day of wastewater and utilizes activated sludge process. The WWTP of hospital has an extended aeration tank after which sludge was settled in settling tank and the treated wastewater was pumped for chlorination. Following the chlorine treatment, the effluent was then discharge through rain-water network [25]. The study isolated the 27 strains of *P. aeruginosa* at different step of wastewater treatment process, that is, in influent wastewater, during activated sludge process, during settling, and from treated effluent. Although, in the samples of chlorination process, none of the isolates of *P. aeruginosa* were detected, it was retrieved in the treated effluent after chlorination. Among 27 isolates of *P. aeruginosa*, 22.2% were multidrug-resistance (MDR) bacteria which confers resistance against aztreonam, clavulanic acid, cefepime, meropenem, polymyxin b, and many more. Other than MDR, 62.9%, 33.3%, and 22.2% strains were resistant to aztreonam, ticarcillin/clavulanic acid, and cefepime, respectively. The study also reveals the presence of strains *P. aeruginosa* (*Pseudomonas panipatensis*) reported to degrade antibiotic and xenobiotic compounds [25].

Prado et al. [41] identified and characterized the enteric virus in effluent of WWTP of two hospitals (WWTP-H1 and WWTP-H2). The WWTP-H1 had an influent flow of 2.54 L/s and utilizes up flow anaerobic sludge blanket reactor (UASB) at hydraulic retention time (HRT) of 8 h. Following the UASB treatment, wastewater was then undergo posttreatment in three serial anaerobic filters. The WWTP-H2 utilizes activated sludge process (HRT of 18 h), followed by chlorination process and had mean influent flow of 5 L/s. The effluent of both of the WWTPs is incorporated into municipal drainage system [41]. The study characterized four viruses in WWTPs, namely rotavirus, human adenovirus (HAdV), hepatitis A virus

(HAV), and norovirus (NoV). The frequency of virus detection was higher in samples WWTP-H2 (100%) than WWTP-H1 (86%). The average viral load in effluent of WWTP-H1 was 2.8×10^3, 2.4×10^3, and 1.9×10^3 for HAdV, NoV, and RV, respectively. The viral load of WWTP-H2 was 8.1×10^2 (NoV), 2.8×10^4 (HAV), 1.4×10^3 (HAdV), and 1.2×10^5 (RV) [77]. The study concluded that both of the WWTPs were not efficient enough for removal of enteric virus and discharge of treated effluent into natural water bodies (Guanabara Bay and Jacarepagua Lagoon) facilitates the dissemination of viruses into the environment [41].

15.5.3 Norway

The presence of pharmaceuticals compounds in VEAS (Vestfjorden Avløpsselskap) WWTP which treats municipal wastewater of Oslo City, Norway, along with the wastewater originated from hospitals (Ullevål University Hospital and Rikshospitalet University Hospital) was studied [42]. The VEAS WWTP treats 100−110 million m^3 of wastewater per year and it is the one of the largest WWTP of Norway which work at HRT of 4 h. The VEAS WWTP involves biological and chemical treatment of wastewater. Following the pretreatment of wastewater which involves screening, the wastewater was precipitated via adding coagulant and polymer. After the sedimentation process, the wastewater is pumped for biological treatment which consist of two-stage fixed biofilm for nitrification and denitrification. Anaerobic digestion and drying is performed for sludge management in VEAS WWTP [43]. The contribution of pharmaceutical load into the VEAS WWTP from the wastewater originated from Ulleval and Rikshospitalet university hospitals was reported [43]. These two hospitals contribute approximately 2% of total pharmaceutical (excluding paracetamol) in VEAS WWTP, the paracetamol contributes ~12% to VEAS WWTP. The presence of pharmaceuticals, namely chlorotetracycline, ifosfamide, trimethoprim, sulfamethoxazole, cyclophosphamide, demeclocycline, ciprofloxacin, tetracycline, 17β-estradiol, oxytetracycline, diclofenac, metoprolol, and ibuprofen was detected in influent and effluent of VEAS WWTP [43]. The influent concentration of pharmaceuticals ranges from <2 to 3550 ng/L. The VEAS WWTP was able to reduce the concentration of pharmaceuticals in the effluent; however, the removal of metoprolol, diclofenac, oxytetracycline, cefuroxime, demeclocycline, and meclocycline was low [43].

15.5.4 Korea

The occurrences and fate of pharmaceuticals and personal care products (PPCPs), prevalence of ARGs in HWWTPs in Korea was documented by many researchers. Sim et al. [82] evaluated the presence of PPCPs in two HWTPs of Republic of Korea located in Ulsan and Busan cities. The HWTP of one hospital utilizes flocculation process followed by an activated carbon adsorption for treatment of HWW. In the second hospital, activated sludge process was utilized after flocculation process for HWW treatment. The treated effluent of both of the HWTPs was then discharge into the environment [82]. The composite concentration of antibiotics, β-blockers, anthelmintic, nonsteroidal antiinflammatory drugs (NSAIDs), and others in influent of both of the HWW ranges from 0.9885 to 78.3 μg/L. The mean concentration of antibiotics and NSAIDs was 74.1 and 78.3 μg/L, respectively. The HWTPs achieve high removal of NSAIDs, β-blockers (> 85%); however, the removal of antibiotic, anthelmintic, and other pharmaceuticals was <75%. Although the HWTP achieves efficient removal of pharmaceuticals (such as NSAIDs and β-blockers), the residual concentration of pharmaceutical in effluent of HWTPs possesses a great risk to environment [82].

Ahn et al. [83] studied the prevalence of ARGs and bacteria community structure of HWPTs of South Korea. The HWTPs situated in Daegu, Korea has two WWTP facility, one for treatment of wastewater generated from human activity (wastewater from kitchen and laundry) in hospitals (HWTP1) and the second WWTP treats wastewater coming from radiology and surgery section (HWTP2). The HWTP1 which treat 600 m^3/day of wastewater involves primary screening and clarification in primary clarifier followed by the biological treatment using activated sludge process. The wastewater is then decanted in secondary clarifier and directed for disinfection process using chlorine. The HWTP2 has an inflow rate of 65 m^3/day and it utilizes oxidation tank followed by coagulation process for primary treatment of wastewater before clarification. Following the primary clarification, the activated sludge process is used for removal of organic contaminant. The wastewater is then directed to secondary clarifier for settling. After the settling, the wastewater is passed through activated carbon filter for removal of toxic chemicals and heavy metals. The treated effluent of both the plant (HWTP1 and HWTP2) discharge into sewage collection system [82]. The analysis of water quality parameters reveals high removal of BOD (> 95%) in the treated effluent of the both HWTPs. The analysis of the toxic chemicals and heavy metals in influent and effluent of HWTP2 revels removal of toxic chemical range from 42% to 100%, having low removal of *n*-hexane (42%) and copper (67%) and high removal of phenol, chromium, and lead. The bacterial community analysis showed variation in community composition of HWTP1 and HWTP2. For instance, Bacteroidetes are the dominant phylum in HWTP1, whereas in HWTP2 the phylum Proteobacteria dominate the bacterial community. The high abundance of ARB in HWTP2 compared to HWTP1 could be due to the high concentration of pharmaceuticals and toxic compound presence in influent of HWTP2 [83].

15.5.5 Vietnam

The investigation of fate of antibiotic in HWTPs of general hospital situated in urban and rural area of Hanoi, Vietnam, was conducted by Lien et al. [84]. The hospital of rural area has 220 beds and the wastewater coming from hospital undergoes onsite treatment in HWTP utilizes filtration, biological treatment, and disinfection process for treatment of wastewater. The HWTP of urban area has physical and chemical treatment facility along with activated sludge process for treatment of HWW [84]. The average antibiotic load on rural and urban HWTP was 654.9 and 93.5 g/month, respectively. In spite of low antibiotic load on urban HWTP, the effluent of both of the HWTPs discharge approximately similar amount of antibiotic in the environment, that is, rural HWTP discharge an average of 34 μg/L and urban HWTP discharge an average of 32.4 μg/L of antibiotic in environment after the treatment. In urban HWTPs, the concentration of antibiotic metronidazole was highest, that is, 258.3 μg/L, followed by ofloxacin whose concentration was 111.1 μg/L. Whereas in rural HWTPs, the antibiotic ciprofloxacin accounts for highest concentration, that is, 66 μg/L, the second most abundant antibiotic was sulfamethoxazole (25.5 μg/L). The removal efficiency of antibiotic in both of the HWTPs (urban and rural was <70% for metronidazole, sulfamethoxazole, ceftazidime, and ciprofloxacin). The high removal of antibiotic trimethoprim (80.5% removal) and spiramycin (72.3%) was observed in rural HWTP. The urban HWTPs had high removal of ofloxacin and spiramycin, that is, 78.7% and 79.6% during the treatment [84]. The detailed description of HWTP with operating condition was not provided in the study; therefore, it was difficult to predict the possible reason behind the discharge of similar number of pharmaceuticals from the HWTPs and low removal of majority of antibiotics.

15.6 Conclusions and perspectives

WHO and concern agencies of the few countries have a fare set of rules and regulations regarding management of HWW. There is a significant noticeable paucity on the literatures regarding exact ways of source separation/segregation of HWWs and the possible impacts of direct or indirect discharges to the environment. These aspects regarding human and environmental health should be urgently addressed by the local/central authorities and hospital managements. Proper regulation formation and their implementation should be done, and proper legislative actions should be warranted to the bodies not obeying the rules. Hospital sewage sludge having high concentrations of helminthes and other pathogens should be treated properly employing aerobic/anaerobic digestion/composting before its disposal. The dewatered sludge could be impounded into the top layers of the root of the reeds, for the mineralization and conversion into soil. Toilet discharges of patients undergoing radioactive therapy should must be segregated and collected separately to avoid further danger due to radioactive emission from sewage. Nomix technology (urine collection at source) can be a better option to collect urine from source itself and then carrying it to the pretreatment unit where important nutrients can be recovered.

Application of MBR combined with activated sludge process is now gaining wide acceptance for HWW treatment due to its high removal capacity for bacteria and antibiotics. However, installation, operation, and maintenance cost of MBR process is relatively higher than other conventional wastewater treatment. Technical and economic issues of HWW treatment plants need to be discussed to develop an efficient and cost-effective way. Research should be focused on developing risk-based approach of treatment technologies recognized as best technology of treatments of HWWs.

The HWW treatment of various countries discussed in the chapter represent the requirement of stringent guidelines for regulation of the pharmaceutical pollutants, ARB, and ARGs in the environment. Even though, metropolitan cities of few countries have separate treatment or onsite treatment facility of HWW, the hospitals of the majority of countries discharge HWW directly to public sewer network without any prior treatment. A very few research investigations concerning treatment of HWW or pharmaceuticals in developed countries such as the United States, United Kingdom, Australia, India, Korea, and other countries were performed. This represent a critical need of research investigation and implantation of separate and optimized treatment process for effective removal of pharmaceuticals.

Abbreviations

ARB antibiotic-resistance bacteria
ARGs antibiotic-resistance genes
BOD biological oxygen demand
COD chemical oxygen demand
HAdV human adenovirus
HAV hepatitis Virus
HRT hydraulic retention time
HWW hospital wastewater
HWWT hospital wastewater treatment
HWWTP hospital wastewater treatment plant
MBR membrane biofilm reactor
MWW municipal wastewater
NSAIDs nonsteroidal antiinflammatory drugs
NV noro virus
PPCPs pharmaceuticals and personal care products
RV rota virus
SARS severe acute respiratory syndrome
TP total phosphorus
TSS total suspended solids
UASB up flow anaerobic sludge blanket reactor
USEPA United State Environmental Protection Agency
UWW urban wastewater
WHO World Health Organization
WWTP wastewater treatment plant

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