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REVIEW ARTICLE

A Study on the Risk Associated with Hospital Waste Water with Best Available Treatment Options

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ABSTRACT

Hospitals consume an important volume of water per day because it is a well-known fact that water is a convenient and universal solvent, which is used to transport waste products away from the site of production and thus hospital waste waters (HWW) which are reciprocally released in large amounts are an incontestable source of many chemical compounds and if untreated these can pose a negative effect on the environment. The most notable feature of HWW is that it does not need to persist in the environment to cause negative effects as it has a variety of chemicals in it which have high rate of transformation / removal and are being continuously introduced in the environment and if these so called "emerging contaminants" (ECs) are monitored regularly for their health impact then they may be candidates for future regulations. Thus HWW significantly change the degree of contamination and pollution loads as compared to sewage waste. Hospital effluents are so a serious problem especially in developing countries like India where there are very few effluent treatment plants installed in hospitals and in most of the health care institutions, this water is directly discharged in the municipal sewage creating havocs in the environment. Considering the importance of this problem literature study was conducted to analyze the adverse implications of raw HWW and offer best environmental practices to overcome this problem by highlighting the merits and demerits of physical, biological and advanced oxidation treatment options. Since conventional wastewater treatment plants are unable to completely remove ECs which as the name suggests are new to the environment so the problem of unavailability of data for ECs present in hospital waste waters such as their types, concentration effects, half-life period, intermediate products and disposal methods all can be solved by using computer generated models and based on the results of these models' treatment options can be selected which may vary from hospital to hospital.
Key words: *Hospital waste water, emerging contaminants, computer generated models, treatment options.*

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INTRODUCTION

Increasing medical facilities and newer innovations in the healthcare sector have proportionally led to an increase in the quantum of waste generation [6]. The waste that is generated during any medical procedure such as diagnosis /treatment / immunization / testing/ research in any type of health care facility i.e. hospitals/ clinics / laboratories is termed as health care waste which if solid is termed as Bio Medical Waste (BMW) and liquid waste is termed as Hospital Waste Water (HWW). HWW's are rich in pharmaceutically active compounds (PhAC's), microorganisms and have high biological oxygen demand (BOD), chemical oxygen demand (COD), NH_3, total N_2 , total suspended solids (TSS) along with toxic heavy metals such as Cd, Cr, Ni, Hg, Sn, Ba, Gd and as such HWWs are difficult to treat using conventional methods.[34], [8], [18], [20]. Most of the contaminants present in small concentrations are called emerging contaminants (ECs) which are highly toxic to human health and aquatic animals [23], [31]. ECs can be synthetic or natural chemicals and there are 6 recognized classes of ECs; (http://www.norman-network.net).

1. Personal Care products (PCPs)/Self Care Articles
2. Endocrine Disrupting Chemicals (EDCs)
3. Pharmaceutical Pollutants (PPs)/Pharmaceutically active compounds
4. Persistent Organic Pollutants (POPs)/Perpetual Organic Contaminants
5. Artificial Sweeteners (ASs)
6. Micro plastics (MPs)

Among these PPs demand special attentio n in India due to various strong reasons; Firstly Indian pharmaceutical market is 3rd largest in the world in volume (Govt. of India, Ministry of Chemicals and Fertilizers, Department of Pharmaceuticals annual report 2020-21); Secondly both prescribed and non prescribed drugs are easily available in the market a sound justification for prevailing self medication Thirdly the bulk of active constituents of pharmaceuticals are found in HWWs, sewage, WWTP, rivers (Indian rivers have the highest concentrations of PPs and their prime source is HWW). PPs/PhACs/pseudo persistents (as these persist in the environment for a longer duration) have some notable characteristics which should be considered before discussing their ecotoxicity effects and these are

1. The classification of PPs is based on their medicinal utility for mankind which is irrelevant in these types of investigations hence they should be classified based on their mode of actions. [7].
2. Ecotoxicity effects are only explored for the prescribed parent drug, the form in which it is excreted (active ingredient or metabolites) after being metabolized in the body are equally important.
3. The biodegradability and bioaccumulative properties of PPs should be taken into account while considering ecotoxicological effects.

Because ECs are so complex and are not known aptly, as there is insufficient knowledge about their toxicity concentrations, half-life period and intermediate metabolites, this is one of the main reasons that only a handful of countries across the world have issued standards or permissible values and protocols related to HWW discharge. Among them is the European Union, Iran, China, Switzerland who have relevant guidelines regarding the wastewater treatment plant (WWTP) discharge limits for ECs. Conventionally designed WWTP mainly works by reducing SS's organic matter & nutrient concentrations. [29].The prime focus of this write up is to generate a fresh insight on the scientific disposal of HWW by emphasizing different hybrid technologies which combine biological treatment methods with tertiary treatment technologies to achieve complete removal of ECs particularly PPs. The review also discusses and updates the different aspects of HWW by highlighting the prevailing methodologies and the upcoming techniques by way of using various computational methods.

MATERIAL AND METHODS

Review of literature using Google Scholar, Scopus and Pubmed databases for HWW was done from 2010-2022. For the study on HWW research articles were scrutinized using the fundamental words as "hospital waste water", "effluents from hospitals", "liquid waste from hospitals", "health care liquid discharge" and "medical center liquid discharge". A manual screening to analyze the trends of the researchers was done. The data on the quantum of H_2O required, amount of waste water generated, characteristics of HWW, regulations and guidelines for safe discharge of HWW and the available treatment options all were collected, compiled and studied carefully to be presented in this study. When the publication scenarios for HWW were studied it was seen that due to advancement in medical sciences and an easy availability of analytical instrumentation laboratories across the globe hospital waste research has gained much importance. Even the contaminants present in nano concentrations are being detected. The studies reviewed were mainly focused on the source, pathway, characterization, treatment and removal of hospital waste. [9], [21], [25]. Separate treatments of HWW and its harmful impacts are being neglected in many countries [32], [3]. More importantly most of the studies on this topic are laboratory based, pilot based studies in removing ECs are lacking. Out of the total studies reviewed 70% were bench scale (lab based), 15% full scale and remaining 15% pilot scale studies. When research articles concentrating on pilot scale studies of HWW were analyzed 67% had adopted biological treatment, 9% had advanced oxidation process (AOP) and 25% studies were based on combined process i.e. biological and AOP for HWW treatment.

3. Hospital Waste Water

3.1. Water Consumption and Waste Water Generation

When data for water consumption and waste water generation for hospitals was analyzed, two reports were considered.

a) Report by the Massachusetts Water Resource Authority, 2020 for the hospitals of the USA having 138-550 beds the water consumed ranged from 156 to 697m^3 day^{-1}.

b) According to the Bureau of Indian Standards (BIS) "for hospitals having less than 100 beds water consumption per patient is app 340 L bed^{-1} day^{-1} and when the number of beds is more than 100 it is 450 L bed^{-1} day^{-1}".

Mean water consumption ranges from 200 to 1200 L bed^{-1} day^{-1}.

The average HWW generated was 466 m^3 day^{-1} for higher income counties and for lower middle income countries it was 95 m^3 day^{-1} (GNI - global national Income, World Bank), in India it was 50 m^3 day^{-1} [30], [26].

3.2 Discharge Options for HWW

HWW can have either direct disposal option, co-treatment or specific pre-treatment for their final discharge.
Direct disposal of HWW into the environment leads to the release of a high concentration of organic matter, pathogens (antibiotic resistant bacteria), ECs in aquatic ecosystems [4], [16].
When HWW is co-treated with municipal WWTPs there is a partial removal of ECs which are then discharged into different water matrices [35] .Also the resultant sludge from these municipal WWTPs is used as a fertilizer hence a fraction of ECs leach into the groundwater from soil.
When HWWs as in higher income group countries are pretreated before their release in municipal WWTP there is a high removal value for organic compounds, pathogens and ECs .

Table-I Highlights the merits and demerits of each option

Discharge Option		Merits	Demerits
a	Direct disposal	Cost effective, non process control.	Pose risk to human health & environment. Excessive nutrients cause eutrophication, Pharmaceuticals and drugs may act as endocrine disruptors, heavy metal poisoning. Source of water and vector borne diseases
b	Co treatment	No direct discharge to the environment.	As HWW is diluted, biodegradative processes are slowed down at the WWTP.
c	Specific Treatment on site + municipal Sewer system	90% reduction in the load. Double treatment ensures maximum safety.	Segregation and strict monitoring by both process operators i.e. hospital staff and public authorities, expensive & complex.

Characterization of HWW with Associated Environmental Health Hazards

Primarily HWW containing pathogens and ECs (PhACs, cytotoxic & mutagenic agents) is termed as domestic discharge and the specific discharge is that portion of HWW that contains hazardous compounds and chemicals giving it a low biodegradability value [33].
Generally HWW has 2 to 3 times higher concentrations of BOD, COD, TSS as compared to municipal waste water [34]. It also contains notable concentrations of pathogens such as E. coli & total coli form that are the vehicles for antibiotic resistance [18]. A wide range of enveloped and non-enveloped infectious viruses are also present in HWW [7] ,[14] ,[37] ,[1]. Among Heavy metals Hg, Pt, Ba, Gd have been continuously detected in HWW [2].
Hospitals release 4 to150 times higher loads of ECs as compared to domestic wastewaters [5]. In ECs special attention is demanded by PhACs and chemical contaminants such as disinfectants and surfactants.

Table 2. Summarizes the most prevalent PhACs present in HWWs.

1.)	Analgesics	acetaminophen, diclofenac, ibuprofen
2.)	Antibiotics	ciprofloxacin, norfloxacin, sulfamethoxazole, ofloxacin, levofloxacin, erythromycin. (67.3% prescriptions in India have antibiotics in them Bhagat et al,2018).
3.)	β Blockers	atenolol, metoprolol, propranolol.
4.)	Hormones	estradiol, estriol and estrone.

Chemical contaminants such as disinfectants and surfactants pose high toxicity to aquatic components of the environment. The most frequently detected surfactant is nonylphenol and disinfectants regularly detected are sodium hypochlorite, povidone iodine and glutaraldehyde [22]. Pertaining to ECs, globally a lacunae regarding guidelines and or regulations for their removal exists [19] .PhACs that contain N_2 atoms such as ciprofloxacin, acetaminophen release toxic fumes of nitrogen oxides during their biodegradation [27]. Similarly PhACs containing fluoride such as norfloxacin release hydrogen fluoride gas which is irritable for eyes, nose and respiratory tract [27]. For calculating the no-effect concentration of different PhAcs on human health, their concentration in aquatic environment is determined and its equivalence to drinking water equivalent limit (DWEL) is seen which is calculated by taking body weight into consideration [10], [13]. For determining the concentrations of ECs in the environment there are 2 approaches theoretical calculations and experimental calculations. To say for when calculating theoretically the predicted concentration of a pharmaceutical in HWW, the amount of each active component of the prescribed drug (M) in grams, the fraction of unchanged active component excreted in urine and feces (F excreted) is divided by the volume of HWW discharged [15]. For experimental calculation each PP is measured in HWW which is a very costly affair [28].

$$\frac{PEC = M(\mathrm{g})F_{(excreted)}}{Vol\ of\ HWW\ disch\arg ed}$$

To calculate DWEL values following parameters are considered.
ADI = acceptable daily intake (mg kg^{-1} day^{-1})
BW= body weight of person in kg
GA= gastro intestinal absorption rate which is taken arbitrarily as 1 for all compounds.
ADWI = average daily water intake (which as per WHO guidelines is taken as 2.552 L day^{-1}).
E_f = frequency of exposure which is taken as 1.
The DWEL values represent the lifelong exposures to ECs for which no severe health effects are likely to be encountered. To measure the ecotoxic potential of ECs to aquatic organisms PNEC values are considered (predicted no effect concentrations) PNEC for above purpose is calculated by dividing half maximal effective conc EC_{50} by all assessment factors of 1000 (Nika et al, 2020). The risk quotient (RQ) or hazard quotient (HQ) can be determined by the measured environmental concentrations (MEC) or predicted environmental concentrations of the considered EC. RQ is taken as the ratio of MEC and PNEC [28]. If RQ is <0.1 no ecotoxic effects are seen, RQ≥ 1 causes severe ecotoxicity effects [24].
Thus these values can be taken as reference values and accordingly rules and regulations pertaining to HWWs should be framed .One of the major point of concern for PhACs and ECs is their biodegradation process in which the parent compound is partially degraded and their may be intermediate transformed products and thus parent compound and transformed products are present together in the ecosystem and consequently their bioaccumulation poses a greater ecological risk.

3.4 HWW Treatment Technologies

There are various types of physical, biological and advanced treatment options available for HWWs. In this section an overview of the removal capacities of these treatment options shall be discussed.
Primary treatment- solid waste removal step-involves sedimentation, coagulation and flocculation for removing solids and organic matter to some extent but it is not effective in the complete removal of ECs [25].
Secondary treatment - biological decomposition step- available secondary treatment options include conventional and advanced. Among these the conventional biological treatment processes include activated sludge process (ASP), constructed wetlands (CW) & trickling filter. The advanced biological treatment processes are MBR and MBBR. A comparison of Conventional and Advanced secondary treatment Processes are given in Table 3 [9].

Table-3 A comparison of conventional and advanced secondary treatment processes

Removal Capacity in % age	Conventional			Advanced biological	
	ASP	CW	Trickling	MBR	MBBR
BOD	97%	96%	90%	95%	
COD	96%	91%	82%	82%	81%
TSS	84%	98%	88%	99%	
ECs	59%	48%	69%	73%	54.5%

Table-4: Summarizes the advantages and disadvantages of conventional and advanced biological treatment options:

Advantages	Disadvantages
Conventional -Simple & cost effective, less energy required, unskilled labor used, high removal of organics and nutrients. Advanced -high removal of ECs, organic matter & nutrients and pathogens, compact requires smaller area, does not require pre primary treatment.	Poor removal of ECs & moderate removal of pathogens, larger area required, rigid treatment & requires primary treatment essentially for removing solids. High capital cost, skilled labor required and has high energy demands.

Tertiary Treatment - extra filtration: - includes advanced oxidation process (AO), adsorption based processes and membrane filtration based processes.

Table-5: Highlights the removal capacity for ECs in percentage for different tertiary processes.

Fenton oxidation	Ozonation	U.V irradiation	Nanofiltration
99%	80.4%	69.1%	91.1%

Table-6: Highlights the advantages and disadvantages of tertiary processes.

Advantages	Disadvantages
Near to complete removal of ECs, pathogens, nutrients, organic matter using MBR, MBBR as a pre-treatment unit.	Results in formation of transformed products and also energy requirement is high.
Less time & complete color & odor is removed from HWW.	Cost intensive requiring skill labor .

3.5 Protocols for Secure Disposal of HWW.

Such guidelines are issued by WHO and environmental protection agencies of only a few higher and upper middle income group countries [2]. As per WHO guidelines HWW can be directly discharged into municipal WWTP if it has the capability of removing at least 95% of bacteria from wastewater or it has primary secondary and tertiary treatment facilities.

Similarly the International commission on radiological protection (ICRP, 2004) had issued standards regarding the secured release of unsealed radionuclides i.e. patients who release radioactive compounds in their excretory fluid after exposure to radioactive treatments.

The US environmental protection agency (EPA) has established the clean water act (CWA) which lay the protocol for agencies like hospitals which are the prime sources of water pollution to follow certain regulations and discharge permits for release of HWW into municipal sewers (indirect discharge) or into rivers and streams (direct discharge).

3.6 Computer Generated Models for Assessment of HWWs

HWWs are a potent source of PhACs and chemicals but the major problem is not their use because this cannot be prevented but the insufficient availability of data in their biodegradation and transport pathways and also lack of knowledge on their ecotoxicity effects upon exposure poses a greater risk [5],[8]. Hence computerized replicas are used to fill the lacking experimental numerical input values and these models are based on the expected probability mechanisms which could be followed by ECs [11], [36].

Theoretical replicas which are based on the relationships between quantity of a particular chemical, its structure and accordingly its activity potential are used to foretell the physico-chemical and biological properties associated with that particular EC. Accordingly these models then are used to predict the concentration of particular EC in hospital effluent and its ecotoxicity level. Recently computer-generated modeling methods such as Fuzzy logic and neural networks are used for HWW analysis.

3.6.1 Fuzzy Logic An AI based system which is a problem solving model dealing with extreme conditions where known entities are converted into numerical and functional values and are used to predict the quality of waste water based on correlation between inputs and output parameters [12].

Fuzzy logic model has been used to foretell the effluent concentration and removal efficiency of 17-β estradiol, COD, suspended solid. Thus it can predict the working efficiency of a treatment system which is used by the operational authorities for HWW treatment.

3.6.2 Neural Network **-** This has been used by the researchers to study the elimination of PhACs such as ciprofloxacin and 17β estradiol [21]. When applying a neural network model to a particular system it identifies the most sensitive and critical parameter present and which influences the overall performance of the system under consideration.

DISCUSSION

Due to the various health care activities and services provided by hospitals they are a major contributor of large quantities of waste water, also the characteristics of HWWs are different from MWW. Generally, parameters like physico-chemical, biological, organic pollutants and nutrients are app 2 to 3 times higher in the HWWs as compared to MWWs. In concomitant with this HWW contain a wide variety of ECs whose concentrations can vary from ngs to mgs, posing serious threat to aquatic species and humans upon their direct discharge into sewer treatment plants (STPs). As discussed only limited data is available on the concentrations of ECs and their effects and as such legislations pertaining to their discharge are also limited to a few developed nations. In this article based on review of literature we have tried to analyze the risk associated with direct discharge of ECs into the STPs and so have offered the advanced treatment methods such AOPs which are combined with pretreatments through ASP and MBR. Such hybrid treatment options were found highly effective. But since these treatment methods are very costly, need high maintenance and skilled labor with regular monitoring during their operation as such before their implementation the concerned hospitals have to do research in this field based on their effluent generation parameters. Such research can be done using computer replicas and then based on the results generated computationally treatment options could be selected.

CONCLUSIONS

The direct discharge of HWWs into rivers or streams or co treatment with MWWs in STPs could be a costly affair in context to hazards based to human health and environment as such pretreatment units in the hospitals especially in multi specialty hospitals should be installed. Before installing such units, each hospital should generate a computerized model based on the characteristics of the effluent generated so that best available treatment options could be utilized.

ABBREVIATIONS

ECs- emerging contaminants, HWW- Hospital wastewater, MWW- municipal wastewater, PhACs - pharmaceutically active compounds, STP- Sewer treatment plant, WWTP-wastewater treatment plant.

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