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The Characterization of Medical Wastewater and Appropriate Treatment Strategies in Dhaka, Bangladesh: A Comparative Analysis of Public Hospitals †

Nazia Hossain, Md. Rakib Hasan Roni * and Abdullah Alif

Department of Chemical Engineering, Bangladesh University of Engineering and Technology, Dhaka 1000, Bangladesh; naziah717@gmail.com (N.H.); abdullahalif1998@gmail.com (A.A.)
* Correspondence: roni06scc@gmail.com; Tel.: +880-1623111082

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Abstract: Dhaka, the economic hub of Bangladesh, houses numerous healthcare facilities, resulting in increased medical waste generation. However, waste management systems in these facilities are often inadequate, posing a threat to public health and the environment. Wastewater characteristics vary regionally, making treatment strategies location-specific. This study characterizes medical waste streams in Dhaka, and suggests appropriate treatment strategies. Twenty samples from four major public hospitals were analyzed for various parameters, including dissolved oxygen (DO), pH, Total Dissolved Solids (TDS), Total Suspended Solids (TSS), color, Total Coliform counts, Chemical Oxygen Demand (COD), and Biochemical Oxygen Demand (BOD_5). Samples were categorized as acceptable, moderate, or highly polluted. Results were compared to the standard values provided by the department of Environment of Bangladesh to find that samples show moderate to high pollution levels in terms of TDS, TSS, color, and bacteria. Effective wastewater treatment strategies are needed to mitigate pollution and ensure health and safety. Treatment recommendations include the implementation of pre-treatment processes such as sedimentation and filtration to remove solids and aeration to increase dissolved oxygen levels. To reduce organic pollution, treatment methods including sequencing batch reactor (SBR), Moving Bed Biofilm Reactor (MBBR), and Membrane Bio Reactor (MBR) were recommended according to the applicability of the processes in respective hospitals. Advanced treatment methods such as activated carbon adsorption and ultraviolet disinfection processes were also suggested to address the specific issues like color and bacterial contamination.

Keywords: Dhaka; medical waste; wastewater treatment; environmental impact

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1. Introduction

Medical waste has become a critical issue in Bangladesh, with indiscriminate disposal causing contamination of water bodies, soil, and the air in Dhaka city. A study indicates that hospitals in Bangladesh generate around 5562 kg of medical waste daily, consisting of 77% non-hazardous and 22.6% hazardous substances. Shockingly, the study highlights the absence of a structured medical waste management system in these hospitals. Some cleaners even salvage items like sharps, saline bags, and test tubes for potential resale [1]. Another study shows that only 9% of hospitals in Bangladesh segregate waste during collection, and merely 11% incinerate the waste. Interestingly, non-government hospitals exhibit better waste management practices than government-run ones [2]. PRISM Bangladesh, a respected national NGO, has introduced a system involving color-coded bins for medical waste segregation and transport to incineration facilities. However, public awareness about these bins remains insufficient [3].

In Gopalganj city, a renowned district of Bangladesh, healthcare facilities do not segregate medical waste into color-coded bins, and residents lack awareness of its dangers.

Throughout the whole city, medical waste is collected using open buckets and plastic bowls, and is often disposed of in municipal dustbins without proper segregation. Liquid waste from all healthcare establishments is released into general sewers [3]. Rajshahi Medical College, which is one of the prominent hospitals of Bangladesh, incinerates approximately 2.5 tons of medical waste, while non-hazardous waste is dumped at designated sites [4].

Hospital liquid discharges fall into four categories: black water (mostly fecal matter and urine), greywater (from washing, containing surfactants and toxins), stormwater, and specific discharges (laboratory waste with radioactive elements, pharmaceutical compounds, and hazardous substances) [5]. The release of these liquid wastes fosters antibiotic-resistant bacteria, or "superbugs" [6].

Efforts to treat liquid waste have been limited in Bangladesh, with direct discharge into sewage systems and rivers being common practice. This study suggests utilizing activated carbon systems and MBBR as potential treatment methods for liquid waste before release into rivers.

2. Methodology

The collected samples were securely stored in the refrigerator within the environmental laboratory at Bangladesh University of Engineering and Technology (BUET). Subsequently, a series of tests were conducted, including pH measurement, Dissolved Oxygen (DO) assessment, Total Dissolved Solids (TDS) analysis, color evaluation, Total Suspended Solids (TSS) determination, and Chemical Oxygen Demand (COD) testing.

1. pH measurement: A pH meter was employed for determining the pH levels of the samples. The pH electrode was rinsed thoroughly and then immersed for readings.
2. Dissolved Oxygen (DO) test: DO levels were measured using a DO meter. The meter's electrode was submerged into the sample, readings were recorded, and the electrode was rinsed with distilled water before repeating the process for additional samples.
3. Total Dissolved Solids (TDS) test: to measure TDS, a TDS meter with an electrode was submerged into the samples, and the corresponding values were recorded.
4. Color measurement: A DR-6000 UV-Vis spectrophotometer was utilized to assess the color of the samples in Pt-Co units.
5. Total Suspended Solids (TSS) test: a DR-6000 UV-Vis spectrophotometer was configured with the "630 suspended solids" program, and a 10 mL sample was inserted into the cell holder. The reading was taken in mg/L.
6. Chemical Oxygen Demand (COD) test: A digestion solution was prepared by adding Ag_2SO_4 to concentrated H_2SO_4 at the rate of 5.5 g Ag_2SO_4/kg H_2SO_4 and allowing it to stand for 2 days. Simultaneously, digestion vessels and 10 mL standard ampules were thoroughly cleaned. Four ampules were filled with 2.5 mL of specific samples (sample 5, sample 9, sample 11, and sample 20) using pipettes. To each ampule, 1.5 mL of $K_2Cr_2O_7$ digestion solution and 3.5 mL of sulfuric acid reagent were added. A blank ampule was prepared with 2.5 mL of distilled water, 1.5 mL of $K_2Cr_2O_7$, and 3.5 mL of sulfuric acid reagent. After adjusting the final volume to 7.5 mL, absorption measurements were taken at the 600 nm wavelength. COD values were calculated by multiplying the minimum absorption by 2.32, using an undigested blank as the reference solution.
7. Biochemical Oxygen Demand (BOD) estimation: Aeration tanks contained 4 L of distilled water, 4 mL each of $MgSO_4$, $FeCl_3$, $CaCl_2$, and phosphate buffer. Air was bubbled into tanks for 30 min. Thirteen 300 mL BOD bottles were cleaned and rinsed. Each received 2 mL of seed solution. Three BOD bottles per sample (sample 5, sample 9, sample 11, and sample 20) received different sample volumes (5 mL, 15 mL, 25 mL, or 50 mL) and the aeration tank solution. The initial DO and temperature were measured with a DO meter. The bottles were sealed without air bubbles, and one served as a blank with dilution water and 2 mL of the seed solution. After five days at 20.4 °C, the DO_5 and temperature were recorded. The formulae used for the calculation were:

$$\text{BOD}_5\ (\text{mg/L}) = \frac{(\text{Initial DO} - \text{DO5}) \times \text{G}}{5}$$

$$\text{G (Dilution factor)} = \frac{\text{Bottle Volume (300 mL)}}{\text{Sample volume}}$$

8. Total Coliform measurement: For this test, m-ColiBlue24 broth was used. Petri dishes and lids were sterilized and placed in hot water for sterility. A sterile absorbent pad was put in each Petri dish, and 2 mL of m-ColiBlue24 was pipetted onto it, covered with the lid. A sterile forceps-inserted membrane filter (grid side up) was positioned in the membrane filter apparatus. The sample was mixed, and 100 mL of the sample (or diluted sample) was vacuum-filtered, with two rinses of the funnel walls using 20 mL sterile buffered dilution water. The filter, grid side up, was placed in the prepared Petri dish with sterile forceps, and the lid was replaced. The dish was inverted and incubated at 35 ± 0.5 °C for 24 h. Post-incubation, colony growth on filters was checked; red colonies indicated total coliforms. The coliform colony count on the filter was obtained by multiplying the count by 10.

3. Results and Discussion

In this section, Table 1 presents the results of the analysis of various water quality parameters for samples collected from four different hospitals in Dhaka, Bangladesh: the Dhaka Medical College Hospital, the Sheikh Hasina National Institute of Burn and Plastic Surgery Hospital, the Shaheed Suhrawardy Medical College and Hospital, and the Mohammadpur Fertility Services and Training Centre, Maternity Hospital. The parameters analyzed include DO, pH, TDS, TSS, Color (Pt-Co), Total Coliform, COD, and BOD_5. Then Table 2 gives the standard values of these parameters according to the Environment Conservation Rules of Bangladesh.

Table 1. Analysis of different water quality parameters.

Source of Sample	Sample No.	DO (ppm)	BOD_5	COD (mg/L)	TDS (mg/L)	TSS (mg/L)	pH	Total Coliform	Color Pt-Co
Dhaka Medical College Hospital	S1	1.44	200	220	570	104	7.08	608	1537
	S2	1.80	150	160	232	22	6.91	750	227
	S3	8.13	210	230	123.5	36	7.77	620	16
	S4	7.00	23	75	163	22	7.45	400	53
	S5	1.91	140	150	750	294	6.74	700	479
Sheikh Hasina National Institute of Burn and Plastic Surgery Hospital	S6	5.05	190	225	1155	70	8.22	420	161
	S7	4.22	150	195	562	57	8.35	300	91
	S8	7.30	51	110	462	40	8.33	640	90
	S9	4.12	160	200	556	50	8.25	350	85
	S10	7.25	75	120	450	70	8.30	595	95
Shaheed Suhrawardy Medical College and Hospital	S11	1.38	160	180	1064	591	5.42	600	2640
	S12	1.57	141	181	457	80	6.47	800	3480
	S13	1.35	185	215	1056	650	5.39	700	2450
	S14	1.39	198	235	980	125	5.50	650	530
	S15	0.38	155	185	1084	259	6.54	560	1800
Mohammadpur Fertility Services and Training Centre, Maternity Hospital	S16	3.13	175	210	434	37	7.79	410	444
	S17	0.92	148	176	564	190	5.94	630	1750
	S18	4.18	97	146	452	32	7.75	800	149
	S19	4.03	160	198	473	16	7.81	360	124
	S20	4.02	155	180	470	19	7.78	390	130

Table 2. Standard values for waste stream parameters at the discharge point into inland surface water [7].

Parameter	Unit	Value Range
DO	mg/L	4.5–8
BOD_5	mg/L	50
COD	mg/L	200
TDS	mg/L	2100
TSS	mg/L	150
pH	mg/L	6–9
Total Coliform	mg/L	<1000

Analyzing the wastewater parameters of the hospitals in comparison to the standard values from "The Environment Conservation Rules, 1997", Bangladesh, we can assess the need for treatment and suggest appropriate treatment strategies for each hospital. The following are the wastewater parameters and proposed suitable treatment processes.

3.1. Dhaka Medical College Hospital

3.1.1. Waste Stream Parameters

- Dissolved Oxygen (DO) levels are below the standard range of 4.5–8 mg/L, indicating low oxygen levels, possibly due to organic matter.
- Biochemical Oxygen Demand (BOD_5) levels are significantly higher than the standard of 50 mg/L, suggesting a high organic load.
- Chemical Oxygen Demand (COD) levels are also above the standard of 200 mg/L, indicating a high concentration of organic and potentially toxic substances.
- Total Dissolved Solids (TDS) levels are within the standard range.
- Total Suspended Solids (TSS) levels are within the standard range.
- pH levels are within the standard range.
- Total coliform levels are within the standard limit of <1000 mg/L.

3.1.2. Treatment Strategy Recommendations

Given the lower TSS and higher organic load, a Moving Bed Biofilm Reactor (MBBR) may be suitable. The Moving Bed Biofilm Reactor (MBBR) process efficiently removes high organic loads. It offers large surface area for microbial growth., enabling it to handle higher loads and achieve good removal efficiency of organic compounds. It is proven to be effective in removing up to 90% Chemical Oxygen Demand (COD) and 95% Biochemical Oxygen Demand (BOD) [8].

3.2. Sheikh Hasina National Institute of Burn and Plastic Surgery Hospital

3.2.1. Waste Stream Parameters

The parameters of this hospital's wastewater are relatively within standard limits.

3.2.2. Treatment Strategy Recommendations

Since most of the parameters are within acceptable limits, minor treatment such as screening and disinfection combining with a simple sequential batch reactor (SBR) may be sufficient to treat the small biological load. SBR is often chosen when there are fluctuations in influent wastewater quality or flow rates. Its batch operation allows for greater flexibility and adaptability to changing conditions. It is suitable for smaller treatment facilities [9].

3.3. Shaheed Suhrawardy Medical College and Hospital

3.3.1. Waste Stream Parameters

- DO levels in the samples are relatively low, indicating poor oxygenation.
- BOD_5 and COD: both levels are relatively high.
- TDS levels are within the standard range.

- TSS levels are significantly high.
- Total Coliform levels are also high.

3.3.2. Treatment Strategy Recommendations

Given the high organic load and suspended solids, a combination of two technologies—Membrane Bio Reactor (MBR) and Moving Bed Biofilm Reactor (MBBR)—can be employed to create a Moving Bed Biofilm Membrane Reactor (MBBMR). This hybrid treatment technique offers enhanced removal efficiency, reduced biofouling compared to MBR, increased effluent production, longer operational lifespan, and decreased waste sludge generation [10].

Since Total Coliform levels exceed the standard values, UV irradiation offers an effective solution. UV-C light is well-known for its ability to deactivate microorganisms, including bacteria and viruses, making it a highly effective method for disinfecting and reducing microbial contamination in medical wastewater streams when applied correctly [11].

3.4. Mohammadpur Fertility Services and Training Centre, Maternity Hospital

3.4.1. Waste Stream Parameters

- DO levels are close to the acceptable range.
- BOD_5 levels are relatively high.
- COD levels are within the standard range.
- TDS levels are within the standard range.
- TSS levels are relatively high.
- Total Coliform levels are relatively high.

3.4.2. Treatment Strategy Recommendations

Since the stream exhibits a high organic load and suspended solids, similar to the conditions observed in the previous hospital (Shaheed Suhrawardy Medical College and Hospital), a strategy like that employed at the hospital, namely MBBMR, can be applied for treating the waste stream [10]. Additionally, UV irradiation should be included as well, given that the total coliform levels exceed the established standards [11].

3.5. Combination of MBBR and MBR

MBBR and MBR systems, known for their compact design, are beneficial for hospitals with limited space for onsite wastewater treatment facilities. The combination of MBBR and MBR ensures comprehensive treatment of both organic matter and pathogenic components. This combination consistently produces high-quality effluent, meeting the required standards [12]. Both systems can be easily automated and controlled, allowing for efficient operation and monitoring, crucial for maintaining consistent treatment performance in a hospital setting. However, these systems have limitations:

- MBBR may struggle with non-biodegradable pollutants like synthetic chemicals, heavy metals, and certain persistent organic pollutants.
- The plastic biofilm carriers in MBBR systems require regular maintenance and replacement. If not maintained properly, fouling or damage to the carriers can affect treatment performance.
- Scaling can occur in MBBR systems if the wastewater has high mineral or metal concentrations, reducing the effectiveness of the biofilm carriers.
- MBBR systems require significant energy for aeration, mixing, and sometimes additional processes like denitrification. This contributes to operational costs and environmental impacts.
- While MBBR relies on biological processes, MBR may need chemicals for membrane cleaning, increasing the operational costs and potential environmental impact.
- Both systems have higher upfront costs due to the need for membrane modules, biofilm carriers, and advanced process control.
- MBR systems also require energy for membrane aeration and maintenance.

- Despite producing less sludge than some conventional processes, sludge disposal remains a concern in MBR and MBBR systems. Proper management and disposal of the generated sludge need to be considered.

4. Conclusions

This study highlights significant variations in the water quality parameters across healthcare facilities in Dhaka, Bangladesh. Elevated levels of organic pollutants, microbial contamination, and color in some samples raise concerns regarding water safety. Implementing tailored wastewater treatment strategies, such as MBBR, MBR, or SBR, is crucial to address specific contamination issues and ensure the provision of clean and safe water for both healthcare facilities and the community.

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