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Status of Hospital Wastewater Management and Regulatory Compliance in Bihar

Abstract : Hospital wastewater is a major concern because it is a potential source of pollution to water bodies, but scant attention has been paid to characterising and treating it. The present study was conducted mainly to generate a database on the characteristics of wastewater being generated from the Government Medical Colleges and Hospitals of Bihar, in view of the new rules (Biomedical Waste Management Rules, 2016). The purpose of the study was to analyse the hospital wastewater characteristics of major hospitals of Bihar and to provide a better strategy for safe treatment and disposal of hospital wastewater. The samples of wastewater were taken, and Physico-chemical parameters including BOD_5, COD, TSS, pH, Oil & grease and Chloride were analysed according to standard protocols (APHA, 2017) and compared with a prescribed standard under the Biomedical Waste Management Rules, 2016. The BOD, COD, TSS, pH, Oil & grease and chloride value of all the hospitals were higher than the prescribed standard. This wastewater can pollute the surface and groundwater; the drinking and irrigation water get unfit for use. Wastewater generated from the hospitals needs to be treated before its disposal as per the existing legislation. Conventional wastewater treatment methods are effective but the high cost and regular maintenance of the conventional wastewater treatment facilities discourage the hospital administration from adopting them. Constructed wetlands are one of the promising technologies that can be easily installed for hospital wastewater treatment. They are cost-effective.

Keywords : Hospital wastewater; Wastewater management; Regulatory compliance; BOD; COD; Bihar.

1. Introduction : Despite growing concern over hospital waste management, little attention has been paid to wastewater generated by hospitals and health care institutions. Hospital wastewaters (HWs) are composed of

the effluents of three different services: (i) general services (kitchen, internal laundry, heating and cooling systems), (ii) diagnostic services (laboratories, radiology departments, outpatient departments, transfusion centres) and (iii) wards like general medicine, surgery, specialities, haemodialysis, etc. (Verlicchi et al., 2012). Government of India, Ministry of Environment, Forest and Climate Change (MoEF&CC), in the year 2016 promulgated new rules for the safe and sound handling, segregation, treatment and disposal of biomedical waste. Hospitals consume large amounts of water drawn from natural sources and municipal supplies. Water is used in healthcare facilities for a wide range of activities, including cleaning, laundering, kitchen operations, laboratory work, offices, wards, and various treatment procedures. After use, the resulting wastewater is broadly termed hospital wastewater. In developing countries such as India, hospitals generate approximately 200–400 L of wastewater per bed per day (Kumari et al., 2020). Hospital wastewater may contain pathogenic microorganisms, partially metabolised pharmaceuticals, disinfectants, detergents, radioactive substances, discarded medicines, and other potentially toxic chemical constituents (Khan et al., 2021). Based on its sources and characteristics, the liquid waste generated from healthcare facilities may include infectious waste such as blood, body fluids, and laboratory cultures; chemically hazardous wastes such as formaldehyde, mercury, solvents, and radioactive isotopes; pharmaceutical wastes consisting of unused or expired medicines; photographic chemicals such as fixer and developer; and wastewater generated from cleaning and washing activities (Biswal, 2013). These contaminants can pose significant risks to human health and the environment and therefore require appropriate treatment before discharge to prevent contamination of surface water, groundwater, and municipal sewage systems (Paulus et al., 2019). Furthermore, sludge generated from on-site treatment facilities may contain pathogenic organisms, including Ascaris eggs and other helminths, necessitating its safe handling and disposal (Yousefi & Ziaei, 2013). Such sludge should not be used as manure for food crops unless properly treated. Microorganisms from hospital wastewater can cause outbreaks of diarrhoea and diseases like cholera (Jerie et al., 2024). In India, hospital wastewater management is regulated primarily under the Bio-Medical Waste Management Rules, 2016, notified under the Environment (Protection) Act, 1986. The Rules require healthcare facilities to segregate and pre-treat liquid chemical waste and ensure its treatment and disposal in accordance with the Water (Prevention and Control of Pollution) Act, 1974. For specified healthcare facilities, discharge standards include pH 6.5–9.0, BOD 30 mg/L, COD 250 mg/L and suspended solids 100 mg/L. State Pollution Control Boards are responsible for authorisation and compliance monitoring. Thus, there is an urgent need to study the characteristics of the HWs, and appropriate nature-based methods shall be employed for the treatment of the HWs. The present study aims to characterise the wastewater generated from major hospitals in Bihar by assessing its key physical, chemical, and biological parameters. It further seeks to evaluate the compliance of hospital wastewater with the applicable legal and regulatory standards, particularly in the context of the Biomedical Waste Management Rules, 2016 and relevant wastewater discharge standards. Based on the wastewater characteristics and regulatory requirements, the study also aims to identify and suggest suitable wastewater treatment and disposal options to ensure safe and environmentally sound management of hospital wastewater.

2. Material and methods : Bihar, located in eastern India, is the third most populous state in the country, with a population of approximately 104.1 million according to the 2011 Census, of which about 88% resided in rural areas. The state covers an area of approximately 94,163 km². Over the past decade, Bihar has witnessed substantial expansion of its healthcare

infrastructure, including the establishment and strengthening of government medical colleges and tertiary-care hospitals. Official records for 2025–26 indicate that Bihar has at least 12 government medical institutions offering MBBS programmes, reflecting the considerable growth of the state's public healthcare system.

For the present study, hospital wastewater samples were collected from eight major government medical colleges and hospitals in Bihar. Information regarding hospital characteristics, wastewater generation, treatment and disposal practices, and biomedical-waste management was obtained through field observations, site visits, institutional records, relevant reports, and discussions with personnel involved in hospital and biomedical-waste management. The selected study sites represented major healthcare institutions across different regions of Bihar and included Indira Gandhi Institute of Medical Sciences (IGIMS), Patna; Patna Medical College and Hospital (PMCH), Patna; Nalanda Medical College and Hospital (NMCH), Patna; All India Institute of Medical Sciences (AIIMS), Patna; Anugrah Narayan Magadh Medical College and Hospital (ANMMCH), Gaya; Darbhanga Medical College and Hospital (DMCH), Darbhanga; Shri Krishna Medical College and Hospital (SKMCH), Muzaffarpur; and Jawaharlal Nehru Medical College and Hospital (JLNMC), Bhagalpur. These institutions include major referral and tertiary-care facilities serving large populations from Bihar and adjoining areas. The government of Bihar currently lists several of these institutions among its major medical colleges and hospitals.

2a. Hospital Wastewater Sampling : Hospital wastewater samples were collected from eight major government/public-sector healthcare institutions in Bihar, namely IGIMS, PMCH, NMCH and AIIMS Patna; ANMMCH Gaya; DMCH Darbhanga; SKMCH Muzaffarpur; and JLNMC Bhagalpur during February 2017 to May 2017. Within each hospital, sampling locations were selected to represent different wastewater-generating sections and collection points, such as wards, laboratories, operation/treatment areas, laundry and kitchen facilities, drainage channels, and the inlet/outlet of the wastewater treatment system, wherever available. Prior to sampling, information on wastewater generation, drainage arrangements, treatment facilities and discharge points was obtained through site observations and discussions with hospital personnel. Samples were collected as grab samples in clean, appropriately labelled containers. The containers were rinsed appropriately before collection, where applicable, and samples were collected without disturbing settled solids or introducing extraneous material. Each sample was labelled with the hospital code, sampling location, date and time of collection.

Immediately after collection, samples intended for physicochemical analysis were placed in an insulated ice box and maintained at approximately 4°C during transportation. Sample handling and preservation followed the recommendations of the Central Pollution Control Board (CPCB) for water and wastewater sampling. CPCB specifies refrigeration and appropriate holding times for parameters such as BOD, COD and TSS, while oil and grease samples require wide-mouth glass containers and acidification. The samples were transported to the laboratory as soon as possible and analysed within the recommended holding period. Particular care was taken to minimise exposure to sunlight, excessive agitation, contamination and prolonged storage. pH was measured immediately at the sampling site because it can change rapidly during storage.

pH was determined onsite using a calibrated digital pH meter. Other physicochemical parameters, namely biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), oil and grease, and chloride, were determined in the laboratory using standard methods for the examination of water and wastewater following APHA, 2017 (Table 1). All analytical instruments were calibrated against certified reference standards prior to analysis.

Reagent blanks and duplicate samples, accounting for approximately 10% of the total samples, were analysed to assess the accuracy and precision of the analytical results. Standard operating procedures were strictly adhered to throughout the analytical process, while data quality was ensured through systematic cross-checking, verification, and proper documentation.

Table 1. Hospital wastewater quality parameters and analytical method

Parameter	Analytical method	Standard method
pH	Electrometric method using calibrated pH meter	APHA, 2017
BOD_5 (mg/L)	5-day incubation method followed by measurement of dissolved oxygen	APHA, 2017
COD (mg/L)	Closed reflux/colorimetric or dichromate reflux method	APHA, 2017
TSS (mg/L)	Filtration through pre-weighed glass-fibre filter followed by drying at 103–105°C	APHA, 2017
Oil & grease (mg/L)	Solvent extraction and gravimetric determination	APHA, 2017
Chloride (mg/L)	Argentometric titration with standard silver nitrate	APHA, 2017

3. Results and discussion

3a. Wastewater collection, treatment and disposal : Field observations revealed that the wastewater collection systems across the investigated hospitals were heterogeneous and varied considerably in terms of drainage configuration, conveyance, segregation, and final disposal. The hospitals generally operated a mixed wastewater collection system, in which wastewater generated from different hospital activities was conveyed through a common drainage network rather than through dedicated pipelines for individual wastewater streams. Both open and covered drains were observed within the hospital premises. Although the majority of the drainage network was covered, open drains were present at several locations, particularly around service areas and other wastewater-generating sections. These open drains were frequently exposed to the indiscriminate disposal of solid waste, resulting in visible accumulation of waste materials within the drainage channels. The solid waste observed in the drains included plaster casts, cotton swabs, pharmaceutical waste, mattresses, bedding materials, plastic bottles, tubes and tubings, and general municipal-type waste. The presence of such materials obstructed the drainage channels at several locations and interfered with the free movement of wastewater, thereby creating conditions conducive to water stagnation, localized accumulation of organic matter, and potential microbial contamination. In addition to affecting the hydraulic performance of the drainage system, the mixing of solid healthcare waste with wastewater increases the possibility of physical and chemical contamination of the wastewater and creates additional occupational risks for workers involved in drainage maintenance.

Wastewater generated from different sections of the hospitals was generally conveyed through a network of drains and subsequently collected through inspection and collection chambers constructed at different points within the hospital premises. These chambers facilitated the collection and redistribution of wastewater towards the downstream drainage system. Blackwater generated from toilets and sanitary facilities was generally directed towards septic tanks. However, no systematic segregation of wastewater streams was observed in the investigated hospitals. In particular, there was no separate collection network for greywater and blackwater, nor was wastewater generated from specialized healthcare activities such as treatment, diagnostic procedures, laboratory operations, and immunization services collected through dedicated drainage lines. Consequently, wastewater originating from different hospital

activities was largely mixed before reaching the final collection or disposal point. Such mixing may result in considerable variability in wastewater characteristics and can facilitate the transfer of potentially hazardous constituents, including pathogens, pharmaceutical residues, disinfectants, chemicals, and other contaminants, from specialized healthcare activities into the general hospital wastewater stream.

A further important observation was the limited availability of dedicated wastewater treatment infrastructure within the investigated hospitals. Among the eight hospitals surveyed, only Indira Gandhi Institute of Medical Sciences (IGIMS), Patna, was found to have its own wastewater treatment facility. The remaining hospitals did not have operational, dedicated wastewater treatment plants for treating the entire hospital wastewater generated within their premises at the time of the field investigation. However, construction of a wastewater treatment plant was observed to be underway at one of the hospitals, indicating an ongoing effort towards establishing wastewater treatment infrastructure. The absence of treatment facilities in most of the investigated hospitals meant that wastewater generated from multiple hospital activities was, in several cases, discharged without adequate treatment. This situation is particularly important because hospital wastewater may contain a complex mixture of conventional organic pollutants as well as pathogenic microorganisms, pharmaceutical residues, disinfectants, chemicals, and other potentially hazardous substances.

The final disposal practices further indicated substantial variation among the hospitals. In the absence of adequate on-site wastewater treatment, untreated or inadequately treated hospital wastewater was observed to be discharged through municipal drainage systems, onto land within or around the hospital premises, or directly into nearby water bodies. In two cases, wastewater was reported or observed to be ultimately discharged into the River Ganga. Discharge into municipal drains may transfer hospital-derived contaminants into the wider urban wastewater network, particularly where downstream sewage treatment infrastructure is inadequate or absent. Similarly, disposal onto land may result in infiltration and potential contamination of soil and groundwater, depending on the hydrogeological conditions and wastewater characteristics. Direct discharge into a major river system presents an additional environmental concern because contaminants originating from healthcare facilities can enter the aquatic environment without adequate treatment. Overall, the field observations indicate that the wastewater management system of the investigated hospitals was characterized by mixed wastewater collection, inadequate segregation of different wastewater streams, solid-waste intrusion into drainage channels, limited dedicated treatment infrastructure, and multiple forms of untreated wastewater disposal. These observations provide an important basis for interpreting the physicochemical characteristics of the wastewater analysed in the present study and highlight the need for improved source segregation, protected drainage infrastructure, regular maintenance of collection chambers, and appropriate on-site wastewater treatment at healthcare facilities.

3b. Physicochemical Characteristics of Hospital Wastewater : The physicochemical characteristics of wastewater collected from the main outlet of the selected hospitals, i.e., the point at which hospital wastewater was discharged into the municipal sewerage system or on land/river, are presented in Table 2.

Table 2. Wastewater quality characteristics of major Govt. College & Hospitals of Bihar

HWs Parameters	IGIMS	NMCH	PMCH	AIIMS	ANMMCH	DMCH	SKMCH	JNMCH	Standard*
BOD (mg/L)	81.2	40.6	81.2	72	142.1	81.2	162.4	40.6	30
COD (mg/L)	460	100	360	510	595	440	400	470	250
TSS (mg/L)	250	128	337	131	231	194	234	134	100

pH	6.6	7.1	7.45	7.325	8.3	8.7	7.7	8.1	6.5-9.0
Oil & grease (mg/L)	1070.2	1018.0	625.48	554.75	861.4	1618.0	2135.6	784.0	10
@Chloride (mg/L)	63.434	45.481	53.978	55.977	206.5	66.973	61.9752	104.95	600

*as prescribed under The Biomedical Waste Management Rules, 2016
@ As prescribed under the WHO standard 1996.

The analysed parameters included BOD_5, COD, pH, TSS, chloride, and oil and grease. Among these parameters, BOD_5 and COD are widely used indicators for assessing the organic load and overall pollution strength of wastewater (Amouei et al., 2020; Ekhaise et al., 2008).

The BOD_5 concentration varied considerably among the investigated hospitals. The minimum concentration (40.6 mg/L) was recorded at PMCH and JLNMC, whereas the maximum concentration (162.4 mg/L) was observed at SKMCH. The minimum and maximum BOD_5 concentrations were approximately 1.35 and 5.48 times higher, respectively, than the applicable discharge standard. The elevated BOD_5 concentrations indicate a considerable biodegradable organic load in the hospital wastewater, which may be associated with the discharge of domestic sewage, body fluids, food residues, cleaning wastewater, and other organic wastes generated within healthcare facilities. In comparison, Singh et al. (2013) reported substantially higher BOD concentrations of 251–1559 mg/L in hospital wastewater from Lucknow, India. A mean BOD concentration of approximately 291 mg/L was reported for hospital wastewater in Hormozgan, Iran (Sarafraz et al., 2007). The comparatively lower BOD_5 concentrations observed in the present study may be related to differences in hospital characteristics, water consumption, dilution, patient load, wastewater collection practices, and the extent of mixing with domestic wastewater.

COD concentrations also exhibited substantial variation among the sampling locations. The lowest COD concentration (100 mg/L) was recorded at NMCH, where the value was below the prescribed discharge standard, whereas the highest concentration (595 mg/L) was observed at ANMMCH. With the exception of NMCH, COD concentrations at all other investigated hospitals exceeded the applicable standard. The mean COD concentration across the study sites was 416.88 mg/L, indicating a considerable overall organic and oxidizable pollutant load. The COD concentrations observed in the present investigation were lower than those reported in several previous studies. Mesdaghinia et al. (2009) reported an average COD concentration of 792 mg/L in hospital wastewater from Tehran, while Sarafraz et al. (2007) reported a mean concentration of 628 mg/L in hospitals of Hormozgan, Iran. Majlesi and Yazdanbakhsh (2008) reported mean BOD and COD concentrations of 348 and 527 mg/L, respectively, for raw wastewater from 70 hospitals in Iran. The COD concentration observed in the present study was therefore within the broad range reported for hospital wastewater elsewhere, although considerable site-to-site variation was evident.

The BOD_5/COD ratio of the hospital wastewater ranged from 0.086 to 0.406 across the eight hospitals. NMCH and SKMCH had the highest ratio (0.406), followed by ANMCH (0.239), PMCH (0.226), DMCH (0.185), IGIMS (0.177), and JNMCH (0.086). The relatively low ratios at most hospitals indicate a considerable fraction of slowly biodegradable or non-biodegradable organic matter in the wastewater. According to the commonly used interpretation, a BOD_5/COD ratio of ≥ 0.5 indicates good biodegradability and suitability for biological treatment, whereas values below 0.5 suggest lower biodegradability (Fresenius et al., 1990; Kajitvichyanukul et al., 2006; Emmanuel et al., 2005). Since none of the investigated hospitals exceeded 0.5, the wastewater may contain appreciable quantities of refractory substances, such

as pharmaceuticals, disinfectants and other chemical constituents, which may limit the efficiency of conventional biological treatment alone. The comparatively higher ratios at NMCH and SKMCH suggest relatively greater biodegradability and potentially better response to biological treatment than the other hospitals. Consequently, assessment of the BOD_5/COD ratio is particularly relevant when selecting an appropriate treatment technology for hospital wastewater.

The pH of the wastewater ranged from 6.6 at IGIMS to 8.7 at DMCH, and all measured values were within the applicable permissible range. The near-neutral to slightly alkaline conditions observed across the hospitals indicate that the wastewater did not exhibit substantial acidic or alkaline characteristics at the time of sampling. Similar ranges have been reported in previous investigations. Singh et al. (2014) reported pH values ranging from 6.13 to 6.78 in hospital wastewater from Lucknow, India, while Meo et al. (2014) reported values between 6.8 and 7.5 in hospitals in Pakistan. Amouei et al. (2015) reported an average pH of 7.6 in wastewater from hospitals affiliated with Babol University of Medical Sciences, Iran. Although the pH values observed in the present study were generally within an acceptable range, substantial deviations from neutral conditions can adversely affect sewerage infrastructure and interfere with biological wastewater treatment processes. Continuous monitoring is therefore important, particularly where chemical disinfectants and laboratory effluents are discharged into the common wastewater network.

Total suspended solids (TSS) represent another important parameter for evaluating wastewater quality because they indicate the concentration of particulate material present in the wastewater. In the present study, TSS concentrations ranged from 128 mg/L at NMCH to 337 mg/L at PMCH. These values corresponded to approximately 1.28 and 3.37 times the applicable discharge standard, respectively. The elevated TSS concentrations may be associated with suspended organic matter, particulate food residues, fibres, sediment, microorganisms, and other solid materials entering the hospital drainage system. The observed range was comparable with values reported in other studies. Singh et al. (2013) recorded TSS concentrations of 155.16–297.6 mg/L in hospital wastewater from Lucknow (Gautam et al., 2026). Mean TSS concentrations of 362 and 184 mg/L have been reported for hospital wastewater from Hormozgan and Tehran, respectively (Sarafraz et al., 2007; Mesdaghinia et al., 2009). The relatively high TSS concentrations observed at several sampling locations highlight the need for effective screening, sedimentation, and other appropriate pretreatment processes before discharge or further biological treatment.

Chloride concentrations in the investigated hospital wastewater ranged from 45.48 mg/L at NMCH to 206.5 mg/L at ANMMCH. The measured concentrations were below the referenced WHO guideline value (WHO, 1996). Chloride in hospital wastewater may originate from domestic sewage, cleaning agents, disinfectants, laboratory activities, and other chemical inputs used within healthcare facilities. The concentration observed in the present study was within the range reported for hospital wastewater elsewhere. Meo et al. (2014) reported chloride concentrations of 70–200 mg/L in hospitals in Pakistan, whereas Emmanuel et al. (2015) reported a wider range of 47–359 mg/L in hospital wastewater from France. Mahvi et al. (2009) reported an average chloride concentration of 267.53 mg/L in wastewater treatment plant effluent from hospitals in Kerman Province, Iran. The variation among studies may be attributed to differences in water consumption, hospital activities, chemical usage, dilution, and wastewater management practices.

Oil and grease showed the most pronounced variation among the investigated parameters. Concentrations ranged from 554.75 mg/L at AIIMS Patna to 2135.6 mg/L at SKMCH. These

concentrations were approximately 55.47 and 213.56 times higher, respectively, than the applicable discharge standard. Such elevated concentrations are of particular concern because oil and grease can form surface films, reduce oxygen transfer, interfere with biological treatment processes, cause clogging of sewerage systems, and adversely affect downstream wastewater treatment units. The presence of oil and grease in hospital wastewater may originate from kitchens, food preparation areas, laboratories, maintenance activities, and other service areas within the hospitals. The markedly high concentrations observed in the present study indicate the need for source-level management and appropriate pretreatment, particularly at locations generating substantial quantities of grease and oily wastewater. Installation and regular maintenance of grease traps or oil-and-grease separation units at relevant source points, together with effective screening and pretreatment before connection to the municipal wastewater network, could reduce the pollutant load entering the sewerage system. Where municipal wastewater treatment plants receive substantial quantities of hospital wastewater, the incoming oil and grease load should also be routinely monitored to ensure that it does not adversely affect treatment performance.

3c. Nature based solution for Hospital Wastewater : The physicochemical characteristics of wastewater observed in the present study, particularly the elevated concentrations of BOD_5, COD, TSS, and oil and grease at several hospitals, indicate the need for appropriate treatment before discharge into municipal drainage systems or the receiving environment. In this context, constructed wetlands (CWs) represent a promising nature-based treatment option for hospital wastewater, particularly where low-energy, decentralised, and environmentally sustainable treatment systems are required. Constructed wetlands are engineered treatment systems that replicate, under controlled conditions, the physical, chemical, and biological processes occurring in natural wetlands. They utilise the combined action of wetland plants, substrate media, microorganisms, filtration, sedimentation, adsorption, and microbial transformation to reduce organic matter, suspended solids, nutrients, and, depending on the system configuration, pathogens and selected emerging contaminants.

Unlike conventional wastewater treatment systems that may require substantial energy, mechanical equipment, chemical inputs, and skilled operation, CWs can be designed as relatively simple and low-energy systems with comparatively lower operation and maintenance requirements. Their ecological characteristics also provide an opportunity to integrate wastewater treatment with landscape restoration and green infrastructure. However, hospital wastewater contains a more complex mixture of contaminants than domestic wastewater, including pharmaceuticals, disinfectants, antimicrobial compounds, pathogens, and other potentially hazardous substances. Therefore, constructed wetlands should not necessarily be considered a stand-alone treatment system for untreated hospital wastewater. Appropriate pretreatment, including screening, grit removal, primary settling, and, where necessary, oil and grease removal, should be incorporated before the wetland stage. A properly designed hybrid configuration combining vertical-flow and horizontal-flow constructed wetlands, followed by appropriate polishing/disinfection, could provide enhanced treatment and greater operational reliability.

The relatively low BOD_5/COD ratios observed in the present study (0.086–0.406) further indicate that a substantial proportion of the organic matter may be slowly biodegradable or non-biodegradable. This highlights the importance of designing a treatment system that provides multiple removal mechanisms rather than relying exclusively on conventional biological degradation. In constructed wetlands, adsorption and filtration by the substrate, microbial

transformation within the rhizosphere, plant-mediated processes, and physicochemical interactions can operate simultaneously. Consequently, a hybrid constructed wetland system may be particularly suitable for the wastewater characteristics observed in the present study, although its performance should be validated through pilot- or field-scale investigations, especially for pharmaceuticals, antimicrobial resistance-related contaminants, pathogens, and other hospital-specific pollutants.

4. Conclusion : The present study demonstrates that hospital wastewater management remains a significant environmental and public-health concern in Bihar. The physicochemical characteristics of the wastewater varied considerably among the investigated hospitals, with several parameters exceeding the applicable discharge standards, indicating that untreated hospital wastewater should not be discharged directly into drains or natural water bodies. Such discharges may adversely affect surface water, groundwater, and their subsequent use for domestic and irrigation purposes. Effective wastewater management therefore requires proper collection, segregation, treatment, and environmentally sound disposal in accordance with the Bio-Medical Waste Management Rules, 2016. Although conventional treatment systems may involve substantial capital, operational, and maintenance requirements, constructed wetlands offer a promising low-energy and potentially cost-effective nature-based treatment option, particularly when appropriately designed and preceded by necessary pretreatment. However, technological solutions alone are insufficient. Strengthened regulatory enforcement, regular monitoring, staff training, waste minimisation, stakeholder responsibility, and adequate financial provisions are essential for sustainable hospital wastewater management in Bihar.

References :

1. Amouei, A. I., Naghipour, D., Taghavi, K., & Estaji, M. (2020). Removal of Metronidazole Antibiotic from Hospital Wastewater by Biosorbent Prepared from Plantain Wood. *Journal of Babol University of Medical Sciences*, *22*(1), 45.
2. APHA. (2017). Standard Methods for the Examination of Water and Wastewater. American Public Health Association.
3. Biswal, S. (2013). Liquid biomedical waste management: an emerging concern for physicians. *Muller Journal of Medical Sciences and Research*, *4*(2), 99-106.
4. Central Pollution Control Board (CPCB). *Sampling Protocol for Water, Wastewater & Soil: Sampling, Preservation & Sample Handling Requirements*. CPCB, Government of India. The CPCB protocol provides recommended containers, preservation conditions and holding times for wastewater parameters.
5. Ekhaise, F. O., & Omavwoya, B. P. (2008). Bacteriological and Physicochemical studies of wastewater discharged from university of Benin Teaching Hospital (UBTH), Benin City into the Environment. *Nigerian Journal of Microbiology*, *22*(1), 1732-1736.
6. Emmanuel, E., Perrodin, Y., Keck, G., Blanchard, J. M., & Vermande, P. (2005). Ecotoxicological risk assessment of hospital wastewater: a proposed framework for raw effluents discharging into urban sewer network. *Journal of hazardous materials*, *117*(1), 1-11.
7. Fresenius, W., & für Wassertechnologie, F. (Eds.). (1990). *Technologie des eaux résiduaires: production, collecte, traitement et analyse des eaux résiduaires*. Springer.
8. Gautam, M., Chaubey, P., Yadav, S. K., & Kumar, S. (2026). Deciphering antibiotic resistance in bacteria from hospital wastewater drains. *Journal of Environmental Biology*, *47*(2), 467-475.

9. Jerie, S., Mutekwa, T. V., Mudyazhezha, O. C., Shabani, T., & Shabani, T. (2024). Environmental and human health problems associated with hospital wastewater management in Zimbabwe. Current Environmental Health Reports, 11(3), 380-389.
10. Kajitvichyanukul, P., & Suntronvipart, N. (2006). Evaluation of biodegradability and oxidation degree of hospital wastewater using photo-Fenton process as the pretreatment method. *Journal of Hazardous Materials*, *138*(2), 384-391.
11. Khan, N. A., Vambol, V., Vambol, S., Bolibrukh, B., Sillanpaa, M., Changani, F., ... & Yousefi, M. (2021). Hospital effluent guidelines and legislation scenario around the globe: A critical review. *Journal of Environmental Chemical Engineering*, *9*(5), 105874.
12. Kumari, A., Maurya, N. S., & Tiwari, B. (2020). Hospital wastewater treatment scenario around the globe. In *Current developments in Biotechnology and Bioengineering* (pp. 549-570). Elsevier.
13. Mahvi, A., Rajabizadeh, A., Fatehizadeh, A., Yousefi, N., Hosseini, H., & Ahmadian, M. (2009). Survey wastewater treatment condition and effluent quality of Kerman province hospitals.
14. Meo, M. I., Haydar, S., Nadeem, O., Hussain, G., & Rashid, H. (2014). Characterization of hospital wastewater, risk waste generation and management practices in Lahore. *Proceedings of the Pakistan Academy of Sciences*, *51*(4), 317-329.
15. Mesdaghinia, A., Naddafi, K., Mahvi, A. H., & Saeedi, R. (2009). Waste management in primary healthcare centres of Iran. *Waste management & research*, *27*(4), 354-361.
16. Paulus, G. K., Hornstra, L. M., Alygizakis, N., Slobodnik, J., Thomaidis, N., & Medema, G. (2019). The impact of on-site hospital wastewater treatment on the downstream communal wastewater system in terms of antibiotics and antibiotic resistance genes. *International journal of hygiene and environmental health*, *222*(4), 635-644.
17. Sarafraz, S., Khani, M. R., & Yaghmaeian, K. (2007). Quality and quantity survey of hospital wastewaters in Hormozgan province.
18. Singh, K. P., Rai, P., Singh, A. K., Verma, P., & Gupta, S. (2014). Occurrence of pharmaceuticals in urban wastewater of north Indian cities and risk assessment. *Environmental monitoring and assessment*, *186*(10), 6663-6682.
19. Singh, R., Mishra, S. S., & Mishra, A. (2013). Hospital solid waste and waste water analysis in Lucknow. *Research in Environment and Life Sciences*, *6*(1), 1-8.
20. Verlicchi, P., Al Aukidy, M., Galletti, A., Petrovic, M., & Barceló, D. (2012). Hospital effluent: investigation of the concentrations and distribution of pharmaceuticals and environmental risk assessment. *Science of the total environment*, *430*, 109-118.
21. Yousefi, Z., & Ziaei Hezarjaribi, H. (2013). Elimination of nematode cysts and ova from hospital sewage by activated sludge process. *Iranica Journal of Energy and Environment*, *4*(4), e64499.

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