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Water quality assessment of the Banong River receiving effluent from Sleman Public Hospital

Muchsin Maulana[1], Didik Setiawan[2], Wonder N. Dlamini[3,4]
[1]Deaprtment of Public Health Science, Faculty of Public Health, Universitas Ahmad Dahlan, Yogyakarta, Indonesia
[2]Sleman Public Hospital, Yogyakarta, Indonesia
[3]Internasional Program in Environmental Science and Technology, National Yang Ming Chiao Tung University, Hsinchu, Taiwan
[4]Institute of Environmental and Occupational Health Sciences, National Yang Ming Chiao Tung University, Hsinchu, Taiwan

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ABSTRACT

Hospital effluent has the potential to release both chemical substances and pathogenic microorganisms into surrounding water bodies, creating hazards for the environment and human health. There is a scarcity of studies in Indonesia that assess the impact of hospital wastewater on river ecosystems using benchmark regulations. This study measured the quality of wastewater at a point 50 meters before discharge and 50 meters after the wastewater treatment plant by analyzing six main parameters of temperature, potential of hydrogen (pH), Biochemical oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), and total suspended solids (TSS), then compared with the water quality standards according to the Regulation of the Governor of the Special Region of Yogyakarta No. 20/2008. This study found that although temperature and pH remained within acceptable ranges, higher BOD, COD, and TDS levels downstream indicated that hospital wastewater was adding to the river's organic and chemical pollution. Improved wastewater treatment processes and consistent monitoring are essential to protect ecosystem integrity and public health.

Corresponding Author:

Muchsin Maulana
Department of Public Health Science, Faculty of Public Health, Universitas Ahmad Dahlan
St. Prof. DR. Soepomo, Umbulharjo, Yogyakarta, Indonesia
Email: muchsin.maulana@ikm.uad.ac.id

1. INTRODUCTION

Hospitals are recognized as significant sources of wastewater and solid waste due to the wide range of medical services and activities they perform. Studies indicate that high-income countries tend to produce larger volumes of wastewater compared to upper and lower-middle-income nations. In contrast, the latter generate greater amounts of biomedical waste (BMW) than their high-income counterparts [1].

The relationship between solid waste disposal methods and water quality indicates that inadequate waste management practices negatively affect the water quality in the study area [2]. The sewage discharge reveals the occurrence of heavy metals in hospital wastewater, even though it does not reveal a high concentration [3]. This study demonstrates that waste disposal sites contribute to the deterioration of surface water quality by altering its physicochemical properties and increasing pollution indicators [4].

Typically, hospital effluents contain diverse physicochemical, biological, nutrient, and organic contaminants, which may pose environmental and public health risks [1]. The main parameters that affect the water quality were potential of hydrogen (pH), temperature, turbidity, total suspended solids (TSS), DO, biochemical oxygen demand (BOD), chemical oxygen demand (COD), N–NH4+, P–PO43-, Fe, and As [5].

Although some parameters remain within permissible limits, the elevated turbidity and BOD values highlight a clear risk of long-term environmental degradation [4].

Sources of pollution significantly affect water quality indicators, with certain sites showing strong impacts from sewage discharge and industrial wastewater effluents [6]. This infectious wastewater potentially leads to environmental disturbances to the rivers and oceans [7]. Assessing and mapping the various determinants affecting hospital liquid medical waste management is very important [8]. There is a scarcity of studies in Indonesia that assess the impact of hospital wastewater on river ecosystems using benchmark regulations. Given these concerns, monitoring and managing wastewater discharges into receiving water bodies is essential to safeguard environmental and public health. This study therefore focuses on assessing the water quality of the Banong River as the recipient of effluent from the Sleman Public Hospital wastewater treatment plant.

2. METHOD

2.1. Research design

This study employed a descriptive quantitative research design to describe the water quality of the Banong River, which serves as a receiving water body for the effluent discharged from the wastewater treatment plant (WWTP) of Sleman Regional Public Hospital located in Morangan, Triharjo, Sleman, Yogyakarta Special Region. The research aimed to assess the degree of pollution in the river by analyzing laboratory test results for six key parameters: temperature, pH, BOD, COD, total dissolved solids (TDS), and TSS. The values obtained were then compared against the provincial water quality standards stipulated in Governor Regulation of the Special Region of Yogyakarta No. 20/2008 [9].

2.2. Water sampling technique, location, and period

Water samples were collected using the grab sampling method at two points. Sampling was conducted 50 meters upstream to represent baseline conditions unaffected by effluent and 50 meters downstream to measure the direct impact of the WWTP discharge within the river's mixing zone. The study was conducted along the Banong River in Morangan, Triharjo Village, Sleman Regency, Yogyakarta, from April 2019 to October 2020, during which two sampling events per year were carried out to capture seasonal variations and ensure more reliable and representative water quality data at a location that directly receives effluent from the hospital's WWTP.

2.3. Parameters analyzed and data analysis

The parameters analyzed in this study included:

a) Temperature (°C) test method Indonesian national standards (SNI) 06-6989.23-2005
b) pH SNI (Indonesian national standards) 06-6989.11-2019
c) Biochemical oxygen demand (BOD, mg/L) Indonesian national standards (SNI) 6989.72-2009
d) Chemical oxygen demand (COD, mg/L) Indonesian national standards (SNI) 6989.2-2019
e) Total suspended solids (TSS, mg/L) Indonesian national standards (SNI) 06-6989.3-2004 gravimetric method
f) Total dissolved solids (TDS, mg/L) Indonesian national standards (SNI) 06-6989.3-2004 gravimetric method

Measurements were conducted by the Yogyakarta Regional Public Health Laboratory, analyzed using descriptive statistics, and compared with Yogyakarta Governor Regulation No. 20/2008, with parameter values evaluated against threshold standards, upstream–downstream variations assessed, and, where relevant, a pollution index (PI) calculated to classify water pollution levels in the Banong River.

3. RESULTS AND DISCUSSION

3.1. Temperature

The observation and measurement results of the wastewater temperature parameter from the Sleman Public Hospital WWTP, using the SNI 06-6989.23-2005 testing method, are presented in Table 1. Table 1: The wastewater temperature measurements showed relatively high values compared with the limits set by the governor's regulation. This condition is likely due to the open storage tank being exposed to direct sunlight, which can increase the water temperature. In many cases, healthcare facilities release emerging contaminants (ECs) and microorganisms directly into aquatic environments without adequate treatment, posing significant risks to both environmental health and ecosystem sustainability [10]. The release of untreated effluent into surface waters represents a major risk to both environmental integrity and human health [11]. Using domestic wastewater treatment plants for hospital effluents is not recommended, as conventional systems are unable to

effectively remove many of the unique contaminants present in hospital wastewater [12]. Considering the complex nature of hospital wastewater and its potential to trigger disease outbreaks, rigorous monitoring and proper treatment are essential to avoid adverse social and environmental impacts. The results of this study indicate that most of the discharged effluent parameters did not comply with established discharge standards [13]. The temperature at both upstream and downstream points of the Banong River remained stable at 25-26 ℃ across the four sampling periods, with no difference observed between the two locations. These findings indicate that the WWTP effluent from Sleman Public Hospital does not cause thermal pollution, as all values were within the permissible limits of the water quality standard.

Table 1. Results of the wastewater temperature parameter

No	Date	Sampling points		Mean	Quality standards Yogyakarta Governor Regulation No. 20/2008, Class II water bodies
		50 meters before the wastewater treatment plant outlet	50 meters after the wastewater treatment plant outlet		
1	April 11, 2019	26 ºC	26 ºC	26 ºC	Air temperature ±3 ºC
2	October 1, 2019	26 ºC	26 ºC	26 ºC	
3	May 4, 2020	26 ºC	26 ºC	26 ºC	
4	October 6, 2020	25 ºC	25 ºC	25 ºC	

Source: Primary data

3.2. pH

The observation and measurement results of the acidity pH parameter of the Banong River water, using the SNI 06-6989.11-2019 method, are presented in Table 2. Table 2 shows that the pH measurement results can be considered stable, as they are still within the regulatory range. This is possible due to the temperature being higher than the water's pH. Many pharmaceuticals possess low lipophilicity, making them difficult to eliminate during wastewater treatment. Without proper regulation, their concentrations may surpass the predicted no-effect levels, posing significant risks to both environmental and public health [14]. The direct release of untreated sewage into receiving water bodies contributes significantly to water pollution problems [15]. Greater attention must be directed toward hospital wastewater management, beginning with treatment plant design, due to the high pollution load contained in hospital effluents [16]. Inadequate wastewater treatment may lead to various problems, such as foul odors and increased risks to public health [17]. Discharging this effluent into aquatic environments impacts crucial water quality indicators, such as biochemical BOD, COD, TDS, TSS, and pH [18]. The pH levels in the Banong River consistently meet the water quality requirements for Class II surface waters as defined by Governor Regulation of Yogyakarta No. 20/2008. The data demonstrate that the effluent from Sleman Public Hospital WWTP does not adversely impact the river's pH balance, and the aquatic environment remains within safe limits for both ecological and public health concerns.

Table 2. Measurement results of the acidity pH parameter

No	Date	Sampling points		Mean	Quality standards Yogyakarta Governor Regulation No. 20/2008 Class II Water Bodies
		50 meters before the wastewater treatment plant outlet	50 meters after the wastewater treatment plant outlet		
1	April 11, 2019	7.6	7.5	7.55	
2	October 1, 2019	7.1	7.4	7.25	6.0 – 8.5
3	May 4, 2020	7.7	7.8	77.5	
4	October 6, 2020	7.5	7.6	75.5	

Source: Primary data

3.3. BOD

The observation and measurement results of the BOD parameter defined as the amount of dissolved oxygen required by microorganisms to decompose organic matter under aerobic conditions in the Banong River, using the SNI 6989.72-2009 testing method, are presented in Table 3. Table 3 shows that the highest BOD value of 4.8 was recorded in October 2019 at the point 50 meters downstream of the discharge outlet, likely due to an increased loading from the wastewater treatment plant. Hospital wastewater poses a significant environmental and public health challenge because it serves as a source of both chemical and microbiological contamination [19]. The results indicate that certain physical and chemical parameters of Belik River water, specifically TSS and BOD, exceeded the Class II Water Quality Standards (WQS), while the remaining parameters were within acceptable limits [20]. The polluted areas should be treated to restore

their ecological functions [21]. High concentrations of harmful bacteria, including Escherichia coli, Acinetobacter, Enterococcus, Streptococcus, and Pseudomonas, have been detected in untreated hospital wastewater [22]. The rigorous application of suitable disinfection technologies for hospital wastewater can significantly lower the bacterial load entering urban treatment plants, thereby reducing the spread of resistant pathogens into the environment [23]. The BOD concentrations in the Banong River generally comply with the quality standard for Class II surface waters, except for a single instance in October 2019. This anomaly suggests the possibility of periodic fluctuations in the WWTP's efficiency or changes in influent characteristics. While the river shows resilience in recovering BOD levels shortly afterward, periodic monitoring and evaluation of WWTP performance are recommended to ensure consistent compliance and protect aquatic ecosystems and public health.

Table 3. Measurement results of the BOD parameter

No	Date	Sampling points		Mean	Quality standards Yogyakarta Governor Regulation No. 20/2008 Class II Water Bodies
		50 meters before the wastewater treatment plant outlet	50 meters after the wastewater treatment plant outlet		
1	April 11, 2019	1.1	1.9	1.5	
2	October 1, 2019	1.6	4.8	2.7	3 mg/L
3	May 4, 2020	2.6	2.7	2.65	
4	October 6, 2020	3.0	2.6	2.8	

Source: Primary data

3.4. COD

The COD parameter represents the amount of oxygen required for the chemical decomposition of organic matter in water. High COD levels can reduce the concentration of dissolved oxygen, which may negatively affect aquatic ecosystems. The measurement results of the COD parameter in the Banong River, tested using the SNI 6989.2-2019 method, are presented in Table 4.

Table 4. Measurement results of the COD parameter

No	Date	Sampling points		Mean	Quality standards Yogyakarta Governor Regulation No. 20/2008 Class II Water Bodies
		50 meters before the wastewater treatment plant outlet	50 meters after the wastewater treatment plant outlet		
1	April 11, 2019	4.7	14.3	9.5	
2	October 1, 2019	5.0	15.4	10.2	25 mg/L
3	May 4, 2020	25.7	27.6	26.65	
4	October 6, 2020	29.5	24.2	26.85	

Source: Primary data

Table 4 shows the COD measurements, a significant increase from 2019 to 2020, with an average value of 26, which was likely associated with the rise in COVID-19 patients that contributed to higher volumes and loads of generated wastewater. A sewage treatment plant is also the key point where surface water receives toxic residues [24]. Chemical components in natural water bodies interact within the environment in much more complex ways compared to when they are studied in isolation [25]. The widespread detection of various pharmaceutical compounds in water sources presents risks to both ecosystems and human health, highlighting the urgent need for effective and sustainable remediation approaches [26]. Water treatment is an essential process required before water can be utilized for various purposes, and the chosen technology must be both effective and carefully evaluated from multiple perspectives [27]. Wastewater discharged from four selected PPIs contained high levels of pollutants and heavy metals, indicating the need for tertiary treatment before environmental release [28]. The COD levels in the Banong River generally comply with water quality standards but showed exceedances in mid and late 2020, both upstream and downstream. This suggests that not only the WWTP discharge but also other upstream sources or reduced river self-purification capacity may be contributing to organic/inorganic pollution. The findings highlight the need for integrated catchment-based monitoring and for the WWTP to maintain consistent treatment efficiency, particularly during periods of environmental stress or increased pollutant load.

3.5. TSS

The observation and measurement results of the TSS parameter of the Banong River, using the SNI 06-6989.3-2004 gravimetric method, are presented in Table 5. Table 5 shows that the TSS measurement

results can be considered stable and remain below the allowable quality standards set by the governor's regulation. This condition is likely due to the filtration process in the wastewater treatment system, which effectively removes small particles before the effluent is discharged into the Banong River. Inadequate wastewater management can lead to residual antibiotics persisting in surface waters, thereby heightening the risk of contaminant exposure [29]. Improper solid waste management and the discharge of untreated wastewater in and around the study area contribute to heavy metal contamination [30]. Targeted measures are necessary to eliminate these metals before wastewater is released into the surrounding environment [31]. The data suggest that the effluent from the Sleman Public Hospital WWTP does not significantly increase the TSS levels in the Banong River. All values remained far below the maximum threshold specified by local water quality standards. Therefore, based on TSS measurements, the impact of hospital wastewater discharge on river sediment load is negligible, and the water body remains within acceptable environmental and public health safety limits.

Table 5. Measurement results of the TSS parameter

No	Date	Sampling points		Mean	Quality standards Yogyakarta Governor Regulation No. 20/2008 Class II Water Bodies
		50 meters before the wastewater treatment plant outlet	50 meters after the wastewater treatment plant outlet		
1	April 11, 2019	5	4	4.5	
2	October 1, 2019	7	6	6.5	50 mg/L
3	May 4, 2020	3	6	4.5	
4	October 6, 2020	5	4	4.5	

Source: Primary data

3.6. TDS

The observation and measurement results of the TDS parameter of the Banong River, using the SNI 06-6989.3-2004 gravimetric method, are presented in Table 6. Table 6 shows the TDS parameter measurements, that it is still far below the threshold permitted by the governor's regulations. This is likely due to the high level of diluent in the wastewater, which could originate from sanitation, air conditioning wastewater, and laundry wastewater. The hospital effluents comprise an array of toxic environmental contaminants [32]. Globally, nearly 80% of untreated wastewater is discharged into the environment, contaminating natural ecosystems. The nitrogen and phosphorus it contains disturb aquatic life and cause considerable ecological harm [15]. To safeguard river ecosystems and public health, it is essential for authorities to promptly identify and regulate heavy metal pollution sources, including industrial discharges and agricultural runoff, while enforcing stricter monitoring of water quality and food safety [33]. Wastewater treatment techniques should be adapted to remove organic micro-contaminants from wastewater [34]. Ongoing monitoring of heavy metal levels in both environmental media and living organisms is crucial to ensure long-term protection of ecosystems and public health [35]. The TDS concentrations in the Banong River following the discharge from the Sleman Public Hospital wastewater treatment facility are consistently within the permissible limits as set by Governor Regulation of Yogyakarta No. 20/2008 for Class II waters. Although there is a measurable increase in TDS downstream most notably in October 2019 the levels remain well under the regulatory threshold. These results indicate that the effluent does not significantly degrade water quality in terms of dissolved solids, and the river remains environmentally safe and compliant with public health standards.

Table 6. Measurement results of the TDS parameter

No	Date	Sampling points		Mean	Quality Standards Yogyakarta Governor Regulation No. 20/2008 Class II Water Bodies
		50 meters before the wastewater treatment plant outlet	50 meters after the wastewater treatment plant outlet		
1	April 11, 2019	103	109	104.5	
2	October 1, 2019	126	376	251	1000 mg/L
3	May 4, 2020	120	122	121	
4	October 6, 2020	121	132	126.5	

Source: Primary data

4. CONCLUSION

While temperature and pH remained within safe limits, elevated BOD, COD, and TDS levels downstream suggest that hospital effluent contributes to organic and chemical loading in the Banong River.

Strengthening wastewater treatment and implementing regular monitoring are essential to safeguard environmental and public health. A limitation of this study is that the results may vary depending on whether data is collected during the rainy or dry season. One way to address this is to collect data throughout the year (rainy and dry seasons) to capture full and even variability. A potential policy approach is data triangulation, using multiple methods or data sources (e.g., BMKG rainfall data, interviews, and field measurements) to validate the findings.

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AUTHOR CONTRIBUTIONS STATEMENT

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Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Muchsin Maulana	✓	✓		✓	✓	✓		✓		✓	✓	✓	✓	
Didik Setiawan		✓		✓	✓	✓	✓	✓	✓	✓				✓
Wonder Dlamini					✓		✓			✓			✓	

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

All authors state no conflict of interest.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

DATA AVAILABILITY

The data supporting this study's findings are available from the corresponding author.

REFERENCES

[1] V. K. Parida, D. Sikarwar, A. Majumder, and A. K. Gupta, "An assessment of hospital wastewater and biomedical waste generation, existing legislations, risk assessment, treatment processes, and scenario during COVID-19," *Journal of Environmental Management*, vol. 308, no. December 2021, p. 114609, 2022, doi: 10.1016/j.jenvman.2022.114609.

[2] A. J. Okon, I. B. Inyang, U. M. J. Ugbe, B. N. Ekpenyong, and O. E. Olanrewaju, "Effect of domestic solid waste disposal practices on quality of drinking water sources in some rural communities of Akwa Ibom State, Nigeria," *Environmental Monitoring and Assessment*, vol. 194, no. 10, 2022, doi: 10.1007/s10661-022-10435-8.

[3] N. A. Sakina, A. Sodri, and H. Kusnoputranto, "Heavy metals assessment of hospital wastewater during the COVID-19 pandemic," *International Journal of Public Health Science (IJPHS)*, vol. 12, no. 1, pp. 187–195, 2023, doi: 10.11591/ijphs.v12i1.22490.

4] O. C. Okafor, W. O. Obaze, C. Njoku, and S. C. Udenze, "Effect of waste disposal sites on physicochemical properties of water in selected states of southeast Nigeria," *Environmental Monitoring and Assessment*, vol. 195, no. 6, 2023, doi: 10.1007/s10661-023-11311-9.

[5] N. T. Giao, H. T. H. Nhien, P. K. Anh, and P. Thuptimdang, "Combination of water quality, pollution indices, and multivariate statistical techniques for evaluating the surface water quality variation in Can Tho City, Vietnam," *Environmental Monitoring and Assessment*, vol. 194, no. 11, 2022, doi: 10.1007/s10661-022-10474-1.

[6] V. Sheykhi and N. Samani, "Assessment of water quality compartments in Kor River, Iran," *Environmental Monitoring and Assessment*, vol. 192, no. 8, 2020, doi: 10.1007/s10661-020-08464-2.
[7] A. K. Katare, A. Tabassum, A. K. Sharma, and S. Sharma, "Treatment of pharmaceutical wastewater through activated sludge process—a critical review," *Environmental Monitoring and Assessment*, vol. 195, no. 12, 2023, doi: 10.1007/s10661-023-11967-3.
[8] M. Kaban, T. R. Soeprobowati, S. Suhartono, P. A. Pireno, A. W. Kristanti, and P. H. Sebong, "Informing compliance factors regarding hospitals waste management procedures in Indonesia: a scoping review," *International Journal of Public Health Science (IJPHS)*, vol. 14, no. 1, p. 219, Mar. 2025, doi: 10.11591/ijphs.v14i1.24500.
[9] Gubernur Daerah Istimewa Yogyakarta, "Peraturan Gubernur Daerah Istimewa Yogyakarta Nomor 20 tahun 2008 tentang baku mutu air di Provinsi Daerah Istimewa Yogyakarta," *Peraturan Gubernur Daerah Istimewa Yogyakarta*. 2008.
[10] M. T. Khan *et al.*, "Hospital wastewater as a source of environmental contamination: an overview of management practices, environmental risks, and treatment processes," *Journal of Water Process Engineering*, vol. 41, no. February, p. 101990, 2021, doi: 10.1016/j.jwpe.2021.101990.
[11] A. Bhardwaj, S. Kumar, and D. Singh, "Tannery effluent treatment and its environmental impact: a review of current practices and emerging technologies," *Water Quality Research Journal*, vol. 58, no. 2, pp. 128–152, 2023, doi: 10.2166/wqrj.2023.002.
[12] A. Majumder, A. K. Gupta, P. S. Ghosal, and M. Varma, "A review on hospital wastewater treatment: a special emphasis on occurrence and removal of pharmaceutically active compounds, resistant microorganisms, and SARS-CoV-2," *Journal of Environmental Chemical Engineering*, vol. 9, no. 2, 2021, doi: 10.1016/j.jece.2020.104812.
[13] P. Karungamye, A. Rugaika, K. Mtei, and R. Machunda, "Physicochemical and microbiological characterization and of hospital wastewater in Tanzania," *Total Environment Research Themes*, vol. 8, 2023, doi: 10.1016/j.totert.2023.100075.
[14] N. A. Khan *et al.*, "Hospital effluent guidelines and legislation scenario around the globe: a critical review," *Journal of Environmental Chemical Engineering*, vol. 9, no. 5, 2021, doi: 10.1016/j.jece.2021.105874.
[15] S. A. Bandh and B. Mushtaq, Wastewater treatment technology, *Springer Water*, 2025. doi: 10.1007/978-3-031-86684-5.
[16] M. T. Khan *et al.*, "Potential environmental impacts of a hospital wastewater treatment plant in a developing country," *Sustainability (Switzerland)*, vol. 16, no. 6, 2024, doi: 10.3390/su16062233.
[17] J. Hong, K. H. Cho, V. Presser, and X. Su, "Recent advances in wastewater treatment using semiconductor photocatalysts," *Current Opinion in Green and Sustainable Chemistry*, vol. 36, 2022, doi: 10.1016/j.cogsc.2022.100644.
[18] T. Islam, M. R. Repon, T. Islam, Z. Sarwar, and M. M. Rahman, "Impact of textile dyes on health and ecosystem: a review of structure, causes, and potential solutions," *Environmental Science and Pollution Research*, vol. 30, no. 4, pp. 9207–9242, 2023, doi: 10.1007/s11356-022-24398-3.
[19] C. Cruz-Cruz *et al.*, "Profiling of bacterial communities of hospital wastewater reveals clinically relevant genera and antimicrobial resistance genes," *Microorganisms*, vol. 13, no. 6, Jun. 2025, doi: 10.3390/microorganisms13061316.
[20] M. P. Hadi, L. N. Fadlillah, A. R. Sih Tifani, and V. K. Ramdan, "Heavy metal pollution and water quality assessment in Belik River, Yogyakarta," in *IOP Conference Series: Earth and Environmental Science*, 2019. doi: 10.1088/1755-1315/256/1/012014.
[21] E. P. Lipy *et al.*, "Assessment of heavy metal concentration in water, sediment, and common fish species of Dhalai River in Bangladesh and their health implications," *Biological Trace Element Research*, vol. 199, no. 11, pp. 4295–4307, 2021, doi: 10.1007/s12011-020-02552-7.
[22] M. T. M. H. Hamad and M. E. El-Sesy, "Adsorptive removal of levofloxacin and antibiotic resistance genes from hospital wastewater by nano-zero-valent iron and nano-copper using kinetic studies and response surface methodology," *Bioresources and Bioprocessing*, vol. 10, no. 1, 2023, doi: 10.1186/s40643-022-00616-1.
[23] N. Z. Seguni *et al.*, "Multidrug-resistant Escherichia coli and Klebsiella pneumoniae isolated from hospital sewage flowing through community sewage system and discharging into the indian ocean," *Bulletin of the National Research Centre*, vol. 47, no. 1, 2023, doi: 10.1186/s42269-023-01039-4.
[24] P. Chandran *et al.*, "Biological treatment solutions using bioreactors for environmental contaminants from industrial wastewater," *Journal of Umm Al-Qura University for Applied Sciences*, vol. 11, no. 2, pp. 185–207, 2025, doi: 10.1007/s43994-023-00071-4.
[25] B. M. Saalidong, S. A. Aram, S. Otu, and P. O. Lartey, "Examining the dynamics of the relationship between water pH and other water quality parameters in ground and surface water systems," *PLoS ONE*, vol. 17, no. 1 1, p. e0262117, Jan. 2022, doi: 10.1371/journal.pone.0262117.
[26] Z. A. Mumtaj, A. R. Khan, M. Alsubih, L. Aleya, R. A. Khan, and S. Khan, "Removal of pharmaceutical contaminants from hospital wastewater using constructed wetlands: a review," *Environmental Science and Pollution Research*, vol. 31, no. 9, pp. 12856–12870, 2024, doi: 10.1007/s11356-024-32022-9.
[27] T. Gali Aba Lulesa, D. Beyene, M. Ebba, and G. Kenea, "Water treatment using natural coagulant and electrocoagulation process: a comparison study," *International Journal of Analytical Chemistry*, vol. 2022, 2022, doi: 10.1155/2022/4640927.
[28] P. Sharma, H. M. N. Iqbal, and R. Chandra, "Evaluation of pollution parameters and toxic elements in wastewater of pulp and paper industries in India: a case study," *Case Studies in Chemical and Environmental Engineering*, vol. 5, 2022, doi: 10.1016/j.cscee.2021.100163.
[29] A. N. Ngigi, M. M. Magu, and B. M. Muendo, "Occurrence of antibiotics residues in hospital wastewater, wastewater treatment plant, and in surface water in Nairobi County, Kenya," *Environmental Monitoring and Assessment*, vol. 192, no. 1, 2020, doi: 10.1007/s10661-019-7952-8.
[30] K. P. Shimod, V. Vineethkumar, T. K. Prasad, and G. Jayapal, "Effect of urbanization on heavy metal contamination: a study on major townships of Kannur district in Kerala, India," *Bulletin of the National Research Centre*, vol. 46, no. 1, 2022, doi: 10.1186/s42269-021-00691-y.
[31] J. B. Baranyika, J. Katabarwa, D. K. Nyirimbibi, S. Bakire, and H. Hirwa, "Assessment of the impacts of selected physicochemical and bacteriological parameters of wastewater (hospital effluents) from the university teaching hospital of Butare on the surrounding environment," *Journal of Cleaner Production*, vol. 410, 2023, doi: 10.1016/j.jclepro.2023.137309.
[32] G. Bhandari *et al.*, "A review on hospital wastewater treatment technologies: current management practices and future prospects," *Journal of Water Process Engineering*, vol. 56, 2023, doi: 10.1016/j.jwpe.2023.104516.
[33] S. U. Samad, S. Ghayyur, R. Ullah, S. Ghayyur, S. M. Arshad, and R. Shah, "Assessment of heavy metal contamination in water, soils, and fish tissues from Barandu River, Buner, Pakistan: implications for food safety and human health risk," *Biological Trace Element Research*, 2025, doi: 10.1007/s12011-025-04693-z.
[34] M. Helmecke, E. Fries, and C. Schulte, "Regulating water reuse for agricultural irrigation: risks related to organic micro-contaminants," *Environmental Sciences Europe*, vol. 32, no. 1, 2020, doi: 10.1186/s12302-019-0283-0.
[35] G. Diansyah, Hermansyah, D. Rohendi, and T. Z. Ulqodry, "Risk assessment of heavy metal pollution in water, sediment, and fish from the Musi River estuary, Indonesia," *Environmental Monitoring and Assessment*, vol. 197, no. 9, Sep. 2025, doi: 10.1007/s10661-025-14501-9.

BIOGRAPHIES OF AUTHORS

Muchsin Maulana is a lecturer with more than twelve years of teaching experience at Universitas Ahmad Dahlan, starting to pursue research in the field of waste management, environmental, and public health in general. Has more than thirty scientific publications in national journals, international journals, and proceedings. In addition, he is active as a presenter at scientific seminars at both national and international levels. He can be contacted at email: muchsin.maulana@ikm.uad.ac.id.

Didik Setiawan is public health graduate from Universitas Ahmad Dahlan and has over 20 years of experience at Sleman Regional Hospital, where he currently serves in the Sanitation and Waste Management Department. He can be contacted at email: didiksetiawan2021@gmail.com.

Wonder N. Dlamini is a Ph.D. research scientist, educator, sustainability consultant, and Associate Fellow (Advance HE, UK). He holds a Ph.D. in Environmental Science and Technology from NYCU, with research expertise in nanomaterials, biotechnology, microbiology, soil science, and environmental science. His doctoral research focuses on the application of nanomaterials for microbial inactivation in air, water, and surface environments. He has received multiple international awards and has led projects on sustainable pollution remediation, air quality management, and plant stress mitigation. He is passionate about developing sustainable technologies to address global environmental and public health challenges. He can be contacted at email: wonder.md10@nycu.edu.tw.