Heavy metals assessment of hospital wastewater during COVID-19 pandemic

Nova Amalia Sakina[1], Ahyahudin Sodri[1], Haryoto Kusnoputranto[1,2]
[1]School of Environmental Sciences, Universitas Indonesia, Central Jakarta, Indonesia
[2]Department of Environmental Health, Faculty of Public Health, Universitas Indonesia, Depok, Indonesia

Article Info

Article history:

Received Sep 12, 2022
Revised Nov 11, 2022
Accepted Nov 27, 2022

Keywords:

Heavy metals
Hospital wastewater
COVID-19
Indonesia
Wastewater treatment

ABSTRACT

Hospital wastewater contains heavy metals that threaten environmental and human health through bioaccumulation and biomagnification. Each heavy metal contributes a different impact on human health and the environment. Monitoring the heavy metals in wastewater is essential to prevent those severe impacts. However, it is still rare for a study to assess heavy metals obtained from the discharge of hospital wastewater in Indonesia. Therefore, this study investigated 14 parameters of heavy metals in hospital wastewater. We tested wastewater quality from September 2021 to February 2022, with SNI 6989-59-2008 sampling methods with 14 parameters. Results show that over 14 parameters are still below the threshold value and other previous studies. It might be because the biological treatment used in the hospital wastewater treatment plant (HWWTP) reduces these micropollutants efficiently. The fluidized bed biofilm reactor (FBBR) system is an aerobic process with microorganisms attached to the bio-green. This technique is to form suspensions of solid particles in sparse media with gas streams for chemical or physical processes. The sewage discharge reveals the occurrence of heavy metals in hospital wastewater, even though it does not reveal a high concentration due to the effectiveness of the FBBR system in HWWTP.

Corresponding Author:

Ahyahudin Sodri
School of Environmental Sciences, Universitas Indonesia
Salemba Raya No. 4, Central Jakarta 10430, Indonesia
Email: ahyahudin.sodri@ui.ac.id

1. INTRODUCTION

Hospital wastewater (HWW) contaminant is 5-15 times more toxic and 4-150 times more pollutants compared to municipal wastewater, which contains emerging contaminants and heavy metals [1]-[5]. The hospital generates 200-1,200 L/bed/day that must be treated daily [6]. Most pollutants (detergents, drug residues, disinfectants) found in untreated HWW contain pharmaceutical partially metabolized, pathogenic microorganisms, radioactive elements, toxic chemical compounds, and heavy metals that remain in wastewater resulting in neutral environmental pollution. Heavy metals can threaten the environment with high potentials, such as climate change and eutrophication [7], [8]. Heavy metals such as Hg, Cd, Cr, As, Cu, Ni, and Pb can survive in the environment and cause damage if they accumulate in living things [9]. Although some heavy metals (Cu, Cr, Fe, Mn, Zn) are essential for living things, they must be in proper concentrations [10]. While As, Cd, Co, Pb, and Hg are non-essential and useless roles in living things [7], [9], [11]. Those pollutants can contaminate municipal wastewater, agrochemicals, raw sewage for irrigation, and industrial effluents [12], [13]. Moreover, routine heavy metals exposure can harm human health.

The accumulated micropollutant bought by wastewater can cause a toxicological impact [14], such as neurotoxicity [15], nephrotoxicity [16], carcinogenicity [7], hepatoxicity, immunology toxicity, cardiovascular toxicity, skin toxicity, reproductive toxicity, developmental toxicity, and genotoxicity [17]. Heavy metals can pass to the human body through inhalation, ingestion, or direct contact. This pathway can determine the adverse effect of heavy metals on human health, such as Pb is more dangerous if inhaled or ingested. Most heavy metals, such as Pb, disturb the concentration of gadolinium scandium galluim garnet (GSGG), which trigger the increasing reactive oxygen species (ROS). ROS in high concentrations can cause cell-structural damage to nucleic acids, proteins, lipids, and membranes [18]. The toxicity of heavy metals occurs because of the replacement of the divalent cations ($Fe^{2+,}$ $Mg^{2+,}$ $Ca^{2+)}$ with monovalent (Na^{+}), which interfere with cell biological metabolism. Pb^{2+} can displace Ca, affecting protein kinase C, which regulates nerve excitation and memory storage [17]-[19]. The wastewater that is not treated correctly has the potential to cause a decrease in the quality of aquatic ecosystems and public health [20]-[22]. Decreasing ecosystem quality can have an impact on reducing habitat in water bodies. At the same time, wastewater can become a medium for the spread of diseases or water-borne diseases such as skin and infectious diseases, like COVID-19 [23], [24].

The medical services and the pandemic caused the quantity of hospital wastewater to increase, with a national number of cases of 544 million and the death toll surpassing six million as of early-July 2022 [25]. A massive patient needed to be treated in the hospital caused the quantity of HWW, though it is not significant. The study location is a state hospital that has been a referral for COVID-19 patients since the first case of infection was determined in Indonesia. The bed ocoupation rate (BOR) has increased during this situation. For example, the general hospital in Mimika, Papua, generates 416.8 L/bed/day with BOR 59.75% during the COVID-19. In this study location, the BOR has increased from January (35.56%) to December (71%) 2021. At the same time, wastewater can be the medium of human health illness [26], [27]. Minister of Environment and Forestry Regulation No. 5 of 2014 explains the quality standards of wastewater in various industries, one of which is the activities of health service facilities such as hospitals. In this regulation, hospital wastewater quality standards are regulated in appendix 44 points B for a hospital that treats its own hazardous and toxic waste. While, Ministry of Environment and Forestry Regulation No. 68 of 2016 (general parameters of domestic wastewater in the form of physical, chemical, and biological parameters) describes the physical parameters analyzed in point include temperature, dissolved solids, and suspended solids, while the chemical parameters are pH, biological oxygen demand (BOD), chemical oxygen demand (COD), total suspended solid (TSS), methylene blue active substance (MBAS) Oil and Fat, and Ammonia Nitrogen. Meanwhile, the biological parameter used is total coliform.

Hospital wastewater quality is usually tested with a few parameters. In Indonesia, Rahmat & Mallongi [28] and Karini *et al.* [29] determined the HWW with two characteristics, BOD and COD, based on Government Regulation P.69 of 2010 about Hospital Wastewater Threshold Value, while Verlicchi *et al.* [30] tested ten parameters such as pH, redox potential, total kjeldahl nitrogen (TKN), Total P, Fat and oil, Chlorides, total surfactants, *E.coli,* fecal coliform, and total coliform. The previous study [31] determined five parameters: total dissloved solid (TDS), TSS, BOD, COD, and pH of HWW with an integrated electrocoagulation-membrane process, while Prayitno *et al.* [32] determined nine parameters of HWW. Nevertheless, to the best of our knowledge, no study discusses the characteristics of HWW with over 14 parameters of heavy metals in a certain period in Indonesia.

Although they appear in water in trace amounts, heavy metals are considered the most toxic and widespread components in wastewater effluent [33], [34]. Amongst, Hg and Ba are detected continuously in HWW because of their utilization in diuretic agents in treatment, organ functioning effect, diagnostic agents, and disinfectants [35], [36], which are discharged within 24 h of usage [5]. The treated effluent from the hospital has flowed to the river, where some people live near the body of water. It might be increased the potential for exposure to heavy metals. So, it is necessary to discuss the pollutants with more comprehensive parameters. In 2022, determining the characteristics of wastewater, only 42 articles discuss wastewater on the Indonesian publication index (IPI) website, a resource platform for discovering scholarly publications in Indonesia managed by the Ministry of Research, Technology, and Higher Education of the Republic of Indonesia. They discuss palm oil industry wastewater [37], [38], coal [39], and home industry [40]. However, only two articles discussing hospital wastewater characteristics appear on that website. They determined the same two parameters of HWW and the hospital itself in Indonesia. The first research was conducted in 2018 [28], while the others were conducted in 2020 [29], which is determined based on Government Regulation P.69 of 2010 about Hospital Wastewater Threshold Value. Nevertheless, none of them discusses the characteristics based on heavy metals characteristics.

A large number of patient referrals in state hospitals causes changes in the quantity and quality of wastewater at an unfavorable level for the sustainability of ecosystems and valuable natural resources. Heavy metals can adversely affect human health and the environment, and the minimum study describes many heavy metals' values. Therefore, the research question is, are heavy metals present in hospital wastewater during COVID-19, even if they do not treat their own hazardous and toxic wastewater? So, this study aims to investigate the presence of heavy metals in hospital wastewater during COVID-19 at the study site. The study results could provide a practical reference to the healthcare industry for wastewater management during the COVID-19 pandemic and other infectious diseases epidemic. Furthermore, our results might be helpful also for the policy maker to monitor the implementation of hospital wastewater regulation in the healthcare industry.

2. RESEARCH METHOD

East Jakarta is one of the important cities of the DKI Jakarta Province regarding economy and population. It has 47 hospitals, while this state hospital is one of 4 that accreditated A. This hospital has been the only COVID-19 referral hospital in East Jakarta since the first case, founded in Indonesia. This hospital used the FBBR wastewater treatment method and activated sludge. From previous research, hospital wastewater quality is usually tested with few parameters. Rahmat and Mallongi [28] and Karini *et al.* [29] determined the HWW with two characteristics, BOD and COD, based on Government Regulation P.69 of 2010 about Hospital Wastewater Threshold Value, while Verlicchi [30] tested ten parameters such as pH, redox potential, TKN, Total P, Fat and oil, Chlorides, total surfactants, *E.coli*, fecal coliform, and total coliform. Djajasasmita [31] determined five parameters: TDS, TSS, BOD, COD, and pH of HWW with an integrated electrocoagulation-membrane process, while Kayira and Wanda [41] determined nine parameters of HWW.

Meanwhile, the latest regulation for those parameters is regulation of The Minister of Environment and Forestry P. 68 of 2016 for Domestic Wastewater Threshold. Nevertheless, there is no assessment of heavy metals in hospital wastewater based on the regulation of Minister of Environment No. 5 of 2014. Therefore, this study determined 14 parameters of heavy metals from September 2021 to February 2022.

We used the outlet wastewater sample and brought it to the P.T. Unilab Perdana Environment Laboratory laboratory, which has certified ISO 9001:2015 and KAN No. LP-852. We tested Cr, Cd, Hg, Pb, Sn, As, Se, Ni, Co, Fe, Mn, Ba, Cu, and Zn. Total Cr and Cd parameters have been tested with methods AP Ed. 23rd 3120. B, 3030. E-2017; Hg with mercury analyzer; Pb, Se, Sn, Ni, As, Mn, Zn, Co, Fe, Cu, and Ba with AP Ed. 23rd 3120. B, 3030. E-2017. This study was analyzed descriptively.

3. RESULTS AND DISCUSSION

3.1. Hospital wastewater treatment plant

The activities of the hospital generate 460 m3/day of wastewater. The wastewater flow in Hospital WWTP as shown in Figure 1, while Figure 2 are the hospital wastewater treatment plant that has been certified by the local government since 2018. Figure 2(a) shows the layout of HWWTP. The wastewaters are from toilets, kitchens, laundry, and hospital hygiene, which will be filtered with a grease trap before entering the reservoir pre-treatment process. Then the wastewater enters the fluidized bed biofilm reactor (FBBR) system, as seen in Figure 2(b). A rake screen is installed to set aside waste automatically above the buffer tank. Then, the waste will be burned in an incinerator. The next step is the buffer tank to accommodate and regulate the water flow.

The FBBR is the central part of wastewater treatment using floating media such as bio-ball. Bio-green, where decomposing microorganisms are bred to reduce organic matter. In this process, the wastewater receives a supply of air produced by the air blower flowing into the aeration tank. The wastewater enters the sedimentation tank after going through the aeration process. There is a separation process between water and mud which will be collected in the sludge stabilization tank. At this point, the sludge became hazardous and toxic waste and was transported to the integrated waste management site of hazardous and toxic waste.

Furthermore, the wastewater enters the water-treated tank stage, which functions as temporary storage of treated wastewater, and then enters the effluent tank through an up-flow filter system. The final stage is when the treated wastewater enters the effluent tank. Previously, wastewater was disinfected by adding chlorine. Then the wastewater is removed as effluent and flows into the water body. Most WWTPs have been designed to remove easily or moderately biodegradable carbon, nitrogen, phosphorous compounds, and microbiological organisms but not micropollutants such as pharmaceutical residues or heavy metals [42].

Standard technologies for treating hospital wastewater are activated sludge systems and membrane bioreactors (MBRs) [43]. An activated sludge system is commonly used in hospital wastewater treatment [44]. The activated sludge can remove up to 91.95% of suspended solids suspected to contain heavy metals [45]. However, advanced treatment technologies such as membrane process [31], [46], and advanced oxidation processes such as ozonation, UV/H2O2 [6], and photo-Fenton [47] have been utilized for micropollutant removal in hospital wastewater. The HWWTP in the study location uses the biological-chlorination process, which is FBBR in the secondary process, and chlorination before the treated wastewater is disposed to the river, which is already adequate to reduce the physical-chemicals pollutants in wastewater. However, reusing treated wastewater is still controversial in the hospital due to its potential environmental impact.

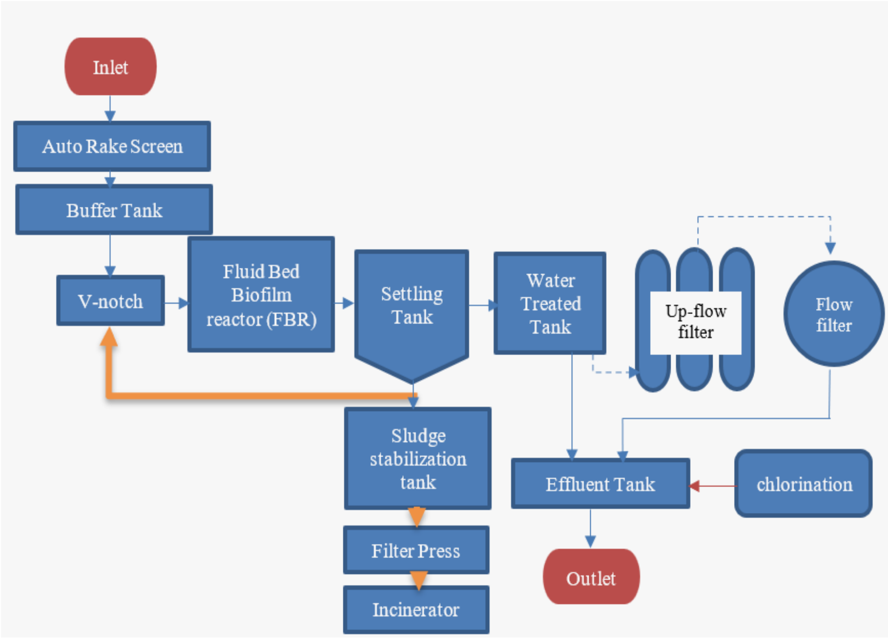

Figure 1. The hospital wastewater treatment plant

Figure 2. The hospital wastewater treatment (a) layout and (b) the FBBR system

3.2. Assessment of heavy metals

Heavy metals present in hospital wastewater might be because of the utilization of heavy metals in the health industry [42], [48]. For example, Hg was detected because of its use in treatment diuretics, disinfectants, and diagnostic agents [42], [49]. Ba is commonly used in hospitals for organ functioning effects, biochemical data, and computed tomography sensitivity [36]. Table 1 explains the previous studies which have mentioned the occurrence of heavy metals in hospital wastewater. All research is primarily done in developing countries such as Iraq, Iran, Mauritania, and Indonesia. They assessed 1-9 heavy metal parameters in hospital wastewater. Although the results show a small amount, it still appears in the hospital wastewater. Some parameters might not be detected due to some heavy metals commonly classified based on their detected concentrations as micropollutants (10^{-6} to 10^{-3} mg L^{-1}) or micropollutants ($>10^{-3}$ mg L^{-1}) [42].

In this research, heavy metals tested are Cr, Cd, Hg, Pb, Sn, As, Se, Ni, Co, Ba, Cu, Zn, Mn, and Fe. These heavy metals come from the utilization of laboratory materials. The heavy metals effluent hospital wastewater characteristics in the study location can be seen in Table 2, which has not exceeded the threshold value.

Table 1. Comparison of the previous study on heavy metals assessment in hospital wastewater

Authors	Country	Type of wastewater	Heavy metals tested	Value (mg/L)
[50]	Iraq	HWW effluent	Cd	Not detected
			Zn,	0.007
			Co	0.011
			Cu	Not Detected
			Ni	0.059
[51]	Iran	HWW inlet/outlet	Pb	0.32±0.05/not detected
			Cd	0.09±0.04/not detected
			Ni	0.10±0.05/not detected
[32]	Indonesia	HWW inlet/outlet	Pb	0.025/<0.001
[34]	Mauritania	HWW effluent	Ar	4.625±1.597
			Pb	3.800±1.742
			Cn	0.050±0.028
			Cr	0.013±0.011
			Cd	Limit of detection
			Cu	60.00±53.54
[49]	Iran	HWW effluent	Pb	14.6±3.6
			Cd	1.8± 0.9
			Cr	33.5 ± 3
			Zn	654± 51
			Co	2.1±0.12
			Hg	4.1±1.7
			Ni	27.4±3
			Fe	1.6±1.2
			Cu	26±1.6

Previous studies also investigated the heavy metals in HWW as shown in Table 1, such as in Iran [49] and Barin [52], though the value is higher than the results in HWW in Indonesia. For example, [34] determine six heavy metals in hospital wastewater in Mauritania, which are As (2.6-6 µg/L), Cn (0.03-0.09 µg/L), Cr (0.005-0.028 µg/L), Pb (2.1-5.4 µg/L), Cd, (<limit detection) Cu (30-140 µg/L). Amongst, only one parameter is below the threshold by WHO because Mauritania does not have regulations about standards for heavy metals in HWW discharge. The As (3 µg/L) and Cu (10 µg/L) in Indonesia are lower than in Mauritania. At the same time, Pb (9 µg/L), Cr (10 µg/L), and Cd (0.8 µg/L) in Indonesia are higher than in Mauritania. During COVID-19, some heavy metals might affect the effectiveness of the infection. Previous research [53] mentions that the abundant Fe in the human body affects the effect of viral replication that causes severe infection.

Table 2. HWW characteristics

Parameters	Threshold value* (mg/L)	Results (mg/L)					
		2021				2022	
		Sept	Oct	Nov	Dec	Jan	Feb
Total chrome	0.5	0.003	0.008	0.02	0.006	0.01	0.006
Cadmium	0.05	<0.0006	0.008	<0.0006	0.0008	<0.0006	<0.0006
Mercury	0.002	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Lead	0.1	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009
Stadium	2	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4
Arsenic	0.1	0.0005	0.0007	0.002	<0.0003	<0.0003	0.0007
Selenium	0.05	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004
Nickel	0.2	0.02	<0.004	0.005	<0.004	<0.004	<0.004
Cobalt	0.4	<0.0007	<0.0007	<0.0007	<0.0007	0.0009	0.0008
Dissolved Iron	5	0.06	0.07	0.06	0.07	0.07	<0.004
Dissolved manganese	2	0.006	0.01	0.04	0.009	0.006	<0.0007
Barium	2	0.1	0.04	0.02	0.01	0.01	0.02
Copper	2	0.008	0.009	0.01	0.008	0.01	0.006
Zinc	5	0.04	0.05	0.07	0.09	0.07	0.05

*Minister of Environment and Forestry Regulation of Republic of Indonesia No. 5 of 2014 appendix 44, point B

The parameters of heavy metals might be reduced and never reach the threshold because the hospital uses biological methods that eliminate biodegradable organic matter efficiently [54], [55]. A previous study by Yan *et al.* [56] gives the same perspective that the practical process of biological chlorination can reduce those parameters. This study location uses FBBR systems to treat hospital wastewater. FBBR is an anaerobic and aerobic process with media. Microorganisms are put in a round-shaped media called bio-green. This media is used for the bacteria to grow up, then protect water quality. This system uses a biofilm that contains microorganisms that produce and secrete polymeric extracellular substances, EPS that are used for stabilizing the microbial community and trapping heavy metals [57], [58]. The research determined two heavy metals, Cd and Zn, in industrial wastewater treated with a biofilm reactor. It is mentioned that the removal efficiency of Zn^{2+} and Cd^{2+} reached 99.845 and 100% [59]. The heavy metals parameters are never above the threshold because of the combination of FBBR and the activated sludge process. The activated sludge process is one of the standard systems in Indonesia for treating hospital wastewater. The system has effectively reduced the sludge that may contain heavy metals through clogging by the microorganism. So, the heavy metals in effluent wastewater are far from the threshold value.

This quantity of pollution, along with other hazardous materials discharged by other pollutants, will endanger public health and degrade the natural resources of the East Jakarta, one of the major urban centers in Indonesia. In addition, the presence of antibiotics and chlorinated organic compounds in hospital wastewater and the disability of wastewater treatment systems will result in many environmental disorders and, consequently, harmful effects on the human health of this city.

4. CONCLUSION

Heavy metals appear in the hospital wastewater even though it does not reveal a high concentration of heavy metal and other parameters. The parameters of heavy metals might be reduced and never reach the threshold due to the FBBR system in the hospital wastewater treatment plant. Although our investigation shows that several heavy metals like Pb (9 µg/L), Cr (10 µg/L), and Cd (0.8 µg/L) are higher than in the previous study, this number is still below the threshold value based on the Indonesia's latest regulation. Monitoring heavy metals in hospital wastewater is essential to prevent bioaccumulation in the environment and living things. Moreover, if the hospital manages its wastewater to contain hazardous and toxic materials, the heavy metals might affect the effect of several infections or diseases. The limitation of this study is that we did not assess the environmental health risk due to the exposure to heavy metals in the population. Therefore, further research for other hospitals is needed to enrich the evidence of heavy metals in hospital wastewater and its impact to the population, which can help to determine wastewater-based epidemiology, which explains the exposure of chemicals or pathogens in a population.

ACKNOWLEDGEMENTS

The authors would like to thank the School of Environmental Science, Universitas Indonesia, for financially supporting this research through grant publication funding No. PKS-0093/UN2.F13.D1/PPM.00.00/2021.

REFERENCES

[1] B. S. Akin, "Contaminant properties of hospital clinical laboratory wastewater: a physiochemical and microbiological assessment," *Journal of Environmental Protection*, vol. 07, no. 05, pp. 635–642, 2016, doi: 10.4236/jep.2016.75057.

[2] A. Amouei, H. A. Asgharnia, A. A. Mohammadi, H. Fallah, R. Dehghani, and M. B. Miranzadeh, "Investigation of hospital wastewater treatment plant efficiency in North of Iran during 2010-2011," *International Journal of the Physical Sciences*, vol. 7, no. 31, pp. 5213–5217, 2012, doi: 10.5897/ijps12.332.

[3] T. Chonova, F. Keck, J. Labanowski, B. Montuelle, F. Rimet, and A. Bouchez, "Separate treatment of hospital and urban wastewaters: a real scale comparison of effluents and their effect on microbial communities," *Science of the Total Environment*, vol. 542, pp. 965–975, 2016, doi: 10.1016/j.scitotenv.2015.10.161.

[4] N. Lusiana, B. Rahadi, and Y. Anggita, "Determination pollution load capacity of ngrowo river as wastewater receiver from hospital activities," in *IOP Conference Series: Earth and Environmental Science*, 2020, vol. 475, no. 1, pp. 1–9. doi: 10.1088/1755-1315/475/1/012067.

[5] N. A. Khan *et al.*, "Occurrence, sources and conventional treatment techniques for various antibiotics present in hospital wastewaters: a critical review," *TrAC - Trends in Analytical Chemistry*, vol. 129, 2020, doi: 10.1016/j.trac.2020.115921.

[6] R. de Oliveira Schwaickhardt, Ê. L. Machado, and C. A. Lutterbeck, "Combined use of VUV and UVC photoreactors for the treatment of hospital laundry wastewaters: reduction of load parameters, detoxification and life cycle assessment of different configurations," *Science of the Total Environment*, vol. 590–591, pp. 233–241, 2017, doi: 10.1016/j.scitotenv.2017.02.218.

[7] B. F. Bakare and G. C. Adeyinka, "Evaluating the potential health risks of selected heavy metals across four wastewater treatment water works in Durban, South Africa," *Toxics*, vol. 10, no. 6, p. 340, 2022, doi: 10.3390/toxics10060340.

[8] L. Corominas *et al.*, "The application of life cycle assessment (LCA) to wastewater treatment: A best practice guide and critical review," *Water Research*, vol. 184, 2020, doi: 10.1016/j.watres.2020.116058.

[9] S. Mitra *et al.*, "Impact of heavy metals on the environment and human health: Novel therapeutic insights to counter the toxicity," *Journal of King Saud University - Science*, vol. 34, no. 3, p. 101865, 2022, doi: 10.1016/j.jksus.2022.101865.

[10] B. Tarnacka, A. Jopowicz, and M. Maślińska, "Copper, iron, and manganese toxicity in neuropsychiatric conditions," *International Journal of Molecular Sciences*, vol. 22, no. 15, 2021, doi: 10.3390/ijms22157820.

[11] Natasha *et al.*, "Health risks of arsenic buildup in soil and food crops after wastewater irrigation," *Science of the Total Environment*, vol. 772, p. 145266, 2021, doi: 10.1016/j.scitotenv.2021.145266.

[12] M. C. Menkiti, C. O. Aniagor, C. M. Onuzulike, M. I. Ejimofor, and S. S. Okonkwo, "Chromium adsorption from petroleum refinery wastewater using biocomposites," *Results in Surfaces and Interfaces*, vol. 8, no. June, p. 100064, 2022, doi: 10.1016/j.rsurfi.2022.100064.

[13] A. Othmani, S. Magdouli, P. Senthil Kumar, A. Kapoor, P. V. Chellam, and Ö. Gökkuş, "Agricultural waste materials for adsorptive removal of phenols, chromium (VI) and cadmium (II) from wastewater: A review," *Environmental Research*, vol. 204, no. August

2021, 2022, doi: 10.1016/j.envres.2021.111916.
[14] A. L. Ahmad, J. Y. Chin, M. H. Z. Mohd Harun, and S. C. Low, "Environmental impacts and imperative technologies towards sustainable treatment of aquaculture wastewater: A review," *Journal of Water Process Engineering*, vol. 46, no. October 2021, p. 102553, 2022, doi: 10.1016/j.jwpe.2021.102553.
[15] P. B. Tchounwou, C. G. Yedjou, A. K. Patlolla, and D. J. Sutton, "Molecular, clinical and environmental toxicicology Volume 3: Environmental Toxicology," *Molecular, Clinical and Environmental Toxicology*, vol. 101, pp. 133–164, 2012, doi: 10.1007/978-3-7643-8340-4.
[16] M. I. Hussain *et al.*, "Blood, hair and feces as an indicator of environmental exposure of sheep, cow and Buffalo to cobalt: A health risk perspectives," *Sustainability (Switzerland)*, vol. 13, no. 14, pp. 1–15, 2021, doi: 10.3390/su13147873.
[17] J. Briffa, E. Sinagra, and R. Blundell, "Heavy metal pollution in the environment and their toxicological effects on humans," *Heliyon*, vol. 6, no. 9, p. e04691, 2020, doi: 10.1016/j.heliyon.2020.e04691.
[18] N. Omidifar *et al.*, "The modulatory potential of herbal antioxidants against oxidative stress and heavy metal pollution: plants against environmental oxidative stress," *Environmental Science and Pollution Research*, vol. 28, no. 44, pp. 61908–61918, 2021, doi: 10.1007/s11356-021-16530-6.
[19] O. Shilpa, K. P. Anupama, A. Antony, and H. P. Gurushankara, "Lead (Pb) induced oxidative stress as a mechanism to cause neurotoxicity in Drosophila melanogaster," *Toxicology*, vol. 462, no. June, p. 152959, 2021, doi: 10.1016/j.tox.2021.152959.
[20] N. Muhammad *et al.*, "Assessment of industrial wastewater for potentially toxic elements, human health (dermal) risks, and pollution sources: A case study of Gadoon Amazai industrial estate, Swabi, Pakistan," *Journal of Hazardous Materials*, vol. 419, no. June, p. 126450, 2021, doi: 10.1016/j.jhazmat.2021.126450.
[21] D. Vitale, M. Morales Suárez-Varela, and Y. Picó, "Wastewater-based epidemiology, a tool to bridge biomarkers of exposure, contaminants, and human health," *Current Opinion in Environmental Science and Health*, vol. 20, p. 100229, 2021, doi: 10.1016/j.coesh.2021.100229.
[22] R. Wathore, A. Gupta, H. Bherwani, and N. Labhasetwar, "Understanding air and water borne transmission and survival of coronavirus: insights and way forward for SARS-CoV-2," *Science of the Total Environment*, vol. 749, p. 141486, 2020, doi: 10.1016/j.scitotenv.2020.141486.
[23] T. E. Ford and S. Hamner, "A perspective on the global pandemic of waterborne disease," *Microbial Ecology*, vol. 76, no. 1, pp. 2–8, 2018, doi: 10.1007/s00248-015-0629-0.
[24] N. Forstinus, N. Ikechukwu, M. Emenike, and A. Christiana, "Water and waterborne diseases: a review," *International Journal of TROPICAL DISEASE & Health*, vol. 12, no. 4, pp. 1–14, 2016, doi: 10.9734/ijtdh/2016/21895.
[25] Badan Informasi Geospasial, "COVID-19 Indonesia Cases," *covid19.big.go.id*, 2021.
[26] D. Zhang *et al.*, "Potential spreading risks and disinfection challenges of medical wastewater by the presence of Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) viral RNA in septic tanks of Fangcang Hospital," *Science of the Total Environment*, vol. 741, p. 140445, 2020, doi: 10.1016/j.scitotenv.2020.140445.
[27] M. Achak, S. Alaoui Bakri, Y. Chhiti, F. E. M'hamdi Alaoui, N. Barka, and W. Boumya, "SARS-CoV-2 in hospital wastewater during outbreak of COVID-19: A review on detection, survival and disinfection technologies," *Science of the Total Environment*, vol. 761, 2021, doi: 10.1016/j.scitotenv.2020.143192.
[28] B. Rahmat and A. Mallongi, "Characteristics and quality study of BOD and COD wastewater of General hospital of labto DF. jeneponto regency pasewang" (in Indonesia: *Studi karakteristik dan kualitas BOD Dan COD limbah cair rumah sakit umum Daerah Lanto DG. Pasewang Kabupaten Jeneponto*)," *Jurnal Nasional Ilmu Kesehatan*, vol. 1, no. 69, pp. 1–16, 2018.
[29] T. A. Karini, D. R. Wijaya, and Z. F. Arranuri, "Characteristics and quality of biologizal oxygen demand (BOD), chemical oxygen demand (COD), hospital liquid waste (a descriptive study at Hospital X Jeneponto Regency (in Indonesia: *Karakteristik dan Kualitas biological oxygen demand (BOD), chemical oxygen demand (COD), limbah cair rumah sakit (Studi deskriptif di Rumah Sakit X Kabupaten Jeneponto*)," *Higiene*, vol. 6, no. 2, pp. 101–107, 2020.
[30] P. Verlicchi, A. Galletti, M. Petrovic, and D. Barceló, "Hospital effluents as a source of emerging pollutants : an overview of micropollutants and sustainable treatment options," *Journal of Hydrology*, vol. 389, no. 3–4, pp. 416–428, 2010, doi: 10.1016/j.jhydrol.2010.06.005.
[31] D. Djajasasmita *et al.*, "High-efficiency contaminant removal from hospital wastewater by integrated electrocoagulation-membrane process," *Process Safety and Environmental Protection*, vol. 164, no. May, pp. 177–188, 2022, doi: 10.1016/j.psep.2022.05.071.
[32] Prayitno, Z. Kusuma, B. Yanuwiadi, R. W. Laksmono, H. Kamahara, and H. Daimon, "Hospital wastewater treatment using aerated fixed film biofilter - Ozonation (Af2b/O3)," *Advances in Environmental Biology*, vol. 8, no. 5, pp. 1251–1259, 2014.
[33] H. Li *et al.*, "Multiple environmental risk assessments of heavy metals and optimization of sludge dewatering: Red mud–reed straw biochar combined with Fe2+ activated H2O2," *Journal of Environmental Management*, vol. 316, no. April, 2022, doi: 10.1016/j.jenvman.2022.115210.
[34] M. B. Ammar *et al.*, "Assessment of heavy metals content in sewage discharges from health structure in Mauritania," *Journal of Pharmacy and Pharmacology*, vol. 10, no. 6, pp. 190–194, 2022, doi: 10.17265/2328-2150/2022.06.002.
[35] H. Rehman, N. A. Khan, H. Hira, and A. Bibi, "Analysis of physicochemical parameters of hospitals wastewater: a case study in Faisalabad, Pakistan," *Pure and Applied Biology*, vol. 9, no. 1, pp. 1191–1198, 2020, doi: 10.19045/bspab.2020.90125.
[36] 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.
[37] A. Shintawati; Hasanudin, Udin; Haryanto, "Characteristic of palm oil mill waste water treatment using semicontinue anaerobic cigar bioreactor" (in Indonesia: *Karakteristik pengolahan limbah cair pabrik minyak kelapa sawit dalam bioreaktor cigar semi kontinu*)," *Teknik Pertanian Lampung*, vol. 6, no. 2, pp. 81–88, 2017.
[38] I. Nursanti, "Characteristics of palm oil mill liquid waste in anaerobic and aero processing" (in Indonesia: *Karakteristik Limbah cair pabrik kelapa sawit pada proses pengolahan anaerob dan aerob*)," *Jurnal Ilmiah Universitas Batanghari Jambi*, vol. 13, no. 4, pp. 67–73, 2013. doi: 10.33087/jiubj.v13i4.324.
[39] R. Fitriyanti, "Characteristics of coal stockpile wastewater" (In Indonesia: *Karakteristik limbah cair stockpile batubara*)," *Jurnal Media Teknik*, vol. 11, no. 1, pp. 12-17. Palembang, 2014.
[40] A. Ngadianto, G. Lukmandaru, D. M. Sari, U. Mardatillah, and D. F. Fitria, "Characteristics of Particle board from peanut shell waste with natural adhesive citric acid with liquid smoke solvent: (in Indonesia: *Karakteristik papan partikel dari limbah kulit kacang tanah dengan perekat alami asam sitrat dengan pelarut asap cair*)," *Jurnal Belantara*, vol. 1, no. 2, pp. 77–88, 2018, doi: 10.29303/jbl.v1i2.73.
[41] F. Kayira and E. M. M. Wanda, "Evaluation of the performance of Mzuzu Central Hospital wastewater oxidation ponds and its effect on water quality in Lunyangwa River, Northern Malawi," *Physics and Chemistry of the Earth*, vol. 123, no. April, p. 103015, 2021, doi: 10.1016/j.pce.2021.103015.

[42] T. S. Oliveira, M. Al Aukidy, and P. Verlicchi, “Occurence of common pollutants and pharmaceuticals in hospital effluents,” in *Hospital Wastewater*, First., D. Bacelo and A. G. Kostianoy, Eds. USA: Springer, 2018, p. 17.
[43] S. M. Hocaoglu, M. D. Celebi, I. Basturk, and R. Partal, “Treatment-based hospital wastewater characterization and fractionation of pollutants,” *Journal of Water Process Engineering*, vol. 43, no. February, p. 102205, 2021, doi: 10.1016/j.jwpe.2021.102205.
[44] C. Chiemchaisri, W. Chiemchaisri, S. Dachsrijan, and C. Saengam, “Coliform Removal in membrane bioreactor and disinfection during hospital wastewater treatment,” *Journal of Engineering and Technological Sciences*, vol. 54, no. 4 na, 2022, doi: 10.5614/j.eng.technol.sci.2022.54.4.1.
[45] M. Custodio, W. Cuadrado-Campó, R. Peñaloza, C. Vicuña-Orihuela, E. Torres-Gutiérrez, and E. Orellana, “Treatment of Hospital wastewater using activated sludge with extended aeration,” *Journal of Ecological Engineering*, vol. 23, no. 11, pp. 24–32, 2022, doi: 10.12911/22998993/152991.
[46] S. Takeshita, H. Farzaneh, and M. Dashti, “Life-cycle assessment of the wastewater treatment technologies in Indonesia’s Fish-Processing Industry,” *Energies*, vol. 13, no. 24, p. 6591, 2020, doi: 10.3390/en13246591.
[47] S. Foteinis, A. G. L. Borthwick, Z. Frontistis, D. Mantzavinos, and E. Chatzisymeon, “Environmental sustainability of light-driven processes for wastewater treatment applications,” *Journal of Cleaner Production*, vol. 182, pp. 8–15, 2018, doi: 10.1016/j.jclepro.2018.02.038.
[48] 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.
[49] A. Amouei, H. Asgharnia, H. Fallah, H. Faraji, R. Barari, and D. Naghipour, “Characteristics of effluent wastewater in hospitals of Babol University of Medical Sciences, Babol, Iran,” *Health Scope*, vol. 4, no. 2, 2015, doi: 10.17795/jhealthscope-23222.
[50] B. O. Abdulsattar, J. O. Abdulsattar, K. H. Rasool, A. R. A. Abdulhussein, and M. H. Abbas, “Study of antimicrobial resistance pattern of Escherichia coli and Klebsiella strains and multivariate analysis for water quality assessment of Tigris River, Baghdad, Iraq,” *Nature Environment and Pollution Technology*, vol. 19, no. 3, pp. 1327–1334, 2020, doi: 10.46488/NEPT.2020.v19i03.050.
[51] R. Foroutan *et al.*, “Characteristics and performance of Cd, Ni, and Pb bio-adsorption using Callinectes sapidus biomass: real wastewater treatment,” *Environmental Science and Pollution Research*, vol. 26, no. 7, pp. 6336–6347, 2019, doi: 10.1007/s11356-018-04108-8.
[52] G. E. Sopoh *et al.*, “Characterization of four university hospitals wastewater in cotonou, Benin,” *Open Journal of Epidemiology*, vol. 11, no. 04, pp. 402–419, 2021, doi: 10.4236/ojepi.2021.114033.
[53] A. Bahrami *et al.*, “Exploring the role of heavy metals and their derivatives on the pathophysiology of COVID-19,” *Biological Trace Element Research*, vol. 200, no. 6, pp. 2639–2650, 2022, doi: 10.1007/s12011-021-02893-x.
[54] Q. Zhou *et al.*, “Total concentrations and sources of heavy metal pollution in global river and lake water bodies from 1972 to 2017,” *Global Ecology and Conservation*, vol. 22, p. e00925, 2020, doi: 10.1016/j.gecco.2020.e00925.
[55] W. S. Chai *et al.*, “A review on conventional and novel materials towards heavy metal adsorption in wastewater treatment application,” *Journal of Cleaner Production*, vol. 296, p. 126589, 2021, doi: 10.1016/j.jclepro.2021.126589.
[56] S. Yan, X. L. Zhang, R. D. Tyagi, and P. Drogui, “Guidelines for hospital wastewater discharge,” in *Current Developments in Biotechnology and Bioengineering*, Elsevier B.V., 2020, pp. 571–597. doi: 10.1016/b978-0-12-819722-6.00016-x.
[57] S. R. Deena *et al.*, “Efficiency of various biofilm carriers and microbial interactions with substrate in moving bed-biofilm reactor for environmental wastewater treatment,” *Bioresource Technology*, vol. 359, no. June, p. 127421, 2022, doi: 10.1016/j.biortech.2022.127421.
[58] X. Hua, L. Wang, L. Zhang, D. Dong, and Z. Guo, “Effects of heavy metal species, concentrations, and speciation on pentachlorophenol sorption by river biofilms,” *Environmental Science and Pollution Research*, vol. 25, no. 21, pp. 20782–20791, 2018, doi: 10.1007/s11356-018-2261-2.
[59] Y. Li *et al.*, “Simultaneous removal of nitrate and heavy metals in a bio fi lm reactor filled with modified biochar,” *Science of the Total Environment*, vol. 851, no. March, 2022, doi: 10.1016/j.scitotenv.2022.158175.

BIOGRAPHIES OF AUTHORS

Nova Amalia Sakina is a Graduate Student at the School of Environmental Science, Universitas Indonesia and a Researcher Assistant in the Cluster of Interaction, Community Engagement, and Social Environment, School of Environmental Science, Universitas Indonesia. She graduated from the Faculty of Public Health, Diponegeoro University, and majored in Environmental Health. She has an ongoing research project collaborated with the University of Melbourne. She can be contacted by email: novaamaliasakina@gmail.com or nova.amalia01@ui.ac.id.

Ahyahudin Sodri is an Assistant Professor in the School of Environmental Science, Universitas Indonesia, and Steering Committee in the 3rd International Symposium of Earth, Environmental Science and Sustainable Development 2022. He got his Master’s Degree in Sensory System Technology from FH Karlsruhe Germany and was awarded a Doctoral degree from the School of Environmental Science, Universitas Indonesia. He has published many articles in reputable journals indexed by Scopus. He leads the research cluster of eco-innovation, cleaner production consumption, life cycle assessment, circular economy, and environmental engineering. He can be contacted by email: ahyahudin.sodri@ui.ac.id.

Haryoto Kusnoputranto is a Full Professor of the Environmental Health Department at Universitas Indonesia, Depok City, and a Lecturer in the School of Environmental Science at Universitas Indonesia, Salemba. He got his Ph.D. in the Public Health Department at the University of Pittsburgh. He has published over two hundred scientific articles in major journals on environmental and Industrial Health, Environmental Health Impact, Environmental Risk Assessment, Urban Environmental Health, Wastewater Management, and Hazardous and Toxic Waste Management. He can be contacted by email: haryoto_k@yahoo.com.