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Development of an IoT-Based Real-Time Monitoring System and LFA to Improve the Efficiency and Performance of the Wastewater Treatment Plant at Udayana University Hospital

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ABSTRACT Indonesia is one of the countries infected by the Coronavirus Disease 2019 (COVID-19) pandemic, which is caused by acute respiratory syndrome virus 2 (SARS-CoV-2). At the end of March 2020, the provincial government of Bali appointed Udayana University Hospital to handle COVID-19 patients because the province has experienced an increase in the number of positive cases. In September 2020, COVID-19 cases in Bali increased by more than 100%, resulting in a higher volume and content of hazardous liquid waste. Furthermore, hazardous liquid waste is the residue of activities that contain substances that can pollute and damage the environment and health, necessitating more efforts in managing the processing of hazardous wastewater produced by the hospital. Based on the background above, this study developed and applied an Internet of Things (IoT) based monitoring system to the Wastewater Treatment Plant (WWTP) in Udayana University Hospital. In principle, the IoT system can be used as a real-time monitoring tool and minimizes direct contact activities of officers' WWTP sites. Moreover, the Liquid Film Aerator (LFA) was applied to improve the efficiency of WWTP. The developed IoT system successfully monitors pH, DO, and real-time temperature, and the monitoring results were presented in a web-based user interface. The result shows better power usage efficiency than conventional aeration. Furthermore, conventional aeration with a root blower requires 619.8 watts to produce 1 mg L^{-1} of DO, while LFA only requires 273.2 watts. The developed systems can be applied to other hospitals or similar wastewater plants that handle COVID-19 cases.

KEYWORDS Udayana University Hospital; COVID-19; IoT-based Real-time Monitoring System; Liquid Film Aerator; Wastewater Treatment Plant

1 INTRODUCTION

The Severe Acute Respiratory Syndrome Coronavirus (SARS-CoV-2) first occurred in Wuhan City, Hubei Province, China. It is transmitted from one person to the other through respiratory droplets and contact routes (Ullah et al., 2021). Indonesia is one of the countries that is infected with the Coronavirus Disease 2019 (COVID-19) pandemic. The government announced the first case of COVID-19 in Indonesia on March 6th. This COVID-19 pandemic has affected people's health and other aspects of their daily life. One of the provinces in Indonesia that have experienced an increased positive number of COVID-19 patients is Bali. This condition has affected the tourism sector, which is the main business in Bali.

The provincial government of Bali specifically appointed Udayana University Hospital to handle COVID-19 patients. However, the condition of COVID-19 patients increases every day, and in September 2020, cases in Bali increased by more than 100%, resulting in increased medical waste. The medical waste consists of body fluids, infusion bottles, antibiotics residual, expired medicines, needles used, and radioactive fluids, all classified as hazardous and toxic waste (Muliarta, 2016; Yuniti et al., 2020).

Hazardous and toxic liquid waste is the residue of activities that contain substances that can pollute, damage, and endanger the environment and health. Poor water waste management can increase disease transmission, pollute the environment, and disturb health (Sutrisno and Meilasari, 2020). Meanwhile, during COVID-19, medical personnel have a high potential to be infected by COVID-19.

Accordingly, the effort to manage the wastewater produced by the hospital has become essential work. One of the solutions to the problem is using the Internet of Things (IoT) system, which can help monitor wastewater performance in real-time (Anh Khoa et al., 2020). The reviews about IoT were well explained by (Hajjaji et al., 2021). The basic concept of IoT is the connection of multiple devices via the internet and their interaction with each other by sharing data or information. Five core entities are identified and defined in IoT, namely, social actors, things, data, networks, events, and processes (Lynn et al., 2020). The explanation of each core is as follows:

(a) Social actors are mainly humans who design and set up the entire IoT system.
(b) Things, in this case, are mainly physical objects, devices, targets, or sensors.
(c) Data are raw information or discrete artifacts that can connect to other devices, including other data, and may be obtained from first, second, or third sources. It detects the existence of an IoT data chain.
(d) Networks are systems of interconnected devices and accommodate networks between different types of IoT systems, such as machine-to-machine (M2M) networks.
(e) Events are the appearance of interest at a given time, physical or virtual space.
(f) Processes are how devices interoperate in the IoT and communicate in domain-specific processes. It includes how the IoT creates, captures, and delivers value or data.

All components and processes mentioned above take place in an infrastructural setting. It is detected by the framework in the IoT system, and auxiliary data and metadata is created and collated at the infrastructural level.

The concept of an IoT system in this study is rather simple. It is an interaction or connection of objects or things (in this case, wastewater), sensors (pH, DO, and temperature sensors), Networks (internet), and users (hospital officers). The IoT system has been applied in many human activities, such as agriculture (Guo, 2021), irrigation, port management (Široka et al., 2021), water quality management and monitoring (Bria et al., 2020; Oberascher et al., 2021; Rajalashmi et al., 2021; Vasudevan and Baskaran, 2021), sewage wastewater monitoring (Kumar and Hong, 2022), pollution monitoring (Arora et al., 2019), wastewater monitoring in university, residential and restaurant (Wen et al., 2018; Anh Khoa et al., 2020; Tanasiev et al., 2021). However, there is less implementation of the IoT to the wastewater problem in hospitals, specifically for hazardous wastewater. The problem of monitoring wastewater during the COVID-19 pandemic has been mentioned by Pulicharla et al. (2021).

The IoT system developed in this study aims to minimize direct contact activities of officers in the field related to COVID-19 situations. IoT technology can also be used to monitor the quality of wastewater remotely and reduce crowds at the hospital. The efficiency of WWTP also needs to be improved, necessitating the application of a Liquid Film Aerator (LFA). The advantage of LFA is that it can work optimally to increase oxygen and increase OTE (oxygen transfer efficiency) roughly 5.3 times higher than conventional aeration (Zhu et al., 2007*a*,*b*). Moreover, finely tuning the structural parameters of the LFAakes dissolved oxygen (DO) saturation of more than 90% in the aeration tank Zhu et al. (2007*a*,*b*). According to Hongprasith et al. (2017), the LFA consumes good efficient energy with 1.2 kg/kWh. In general, the mechanism of oxygen transfer in an LFA system can be summarized into 4 patterns, namely 1) Conventional, 2) Bubble collection, 3) Bubble recirculation, and 4) Bubble-Liquid Foam mechanism (Hongprasith et al., 2017).

The Udayana University Hospital started operating in 2013, opening health services for the public as a first-level health service provider. The government of Bali Province appointed Udayana University hospital to handle COVID-19 patients in Bali in March 2020. Consequently, the hospital generates an increase in toxic and hazardous liquid waste. The wastewater management technology through Wastewater Treatment Plant (WWTP)

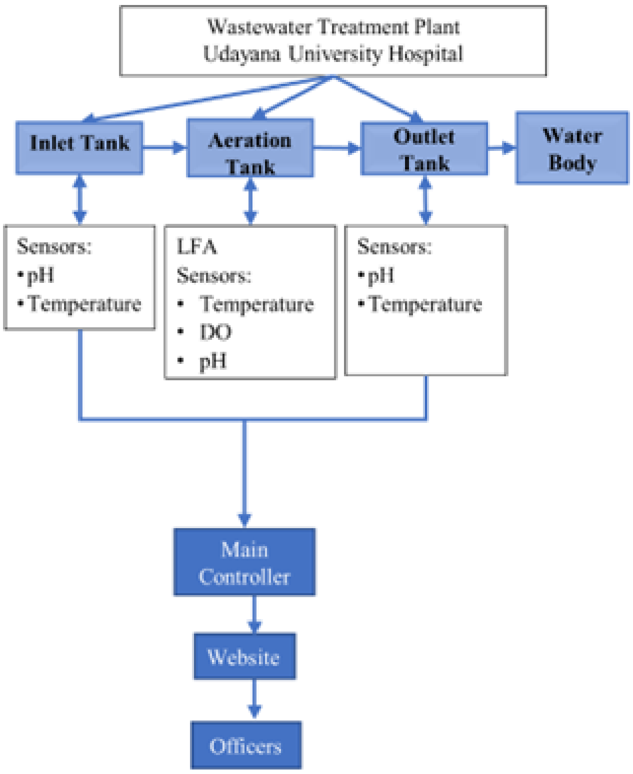

Figure 1 Monitoring design

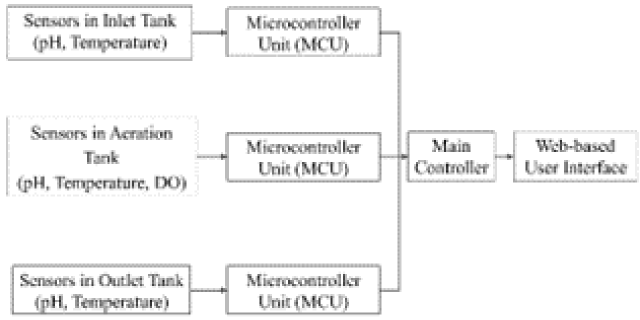

Figure 2 IoT system diagram

Figure 3 Location of WWTP Udayana University Hospital

is currently constrained because it requires high cost and energy and does not have real-time monitoring technology. Without a strong IoT-enabled IT system, WWTP in Udayana University Hospital management suffered from multiple inefficiencies. Before the implementation of the WWTP online real-time monitoring system, the Udayana University Hospital was managed manually and required daily site inspections. This management framework resulted in multiple problems, and the WWTP was difficult to supervise.

Based on the problems mentioned above at WWTP in Udayana University hospital, a collaborative study was proposed between Udayana University Hospital (Bali, Indonesia) and Earth Creative Co., Ltd (Yamaguchi, Japan). This study aims to develop and establish an IoT-based real-time monitoring system to reduce or minimize direct contact activities of officers in the WWTP. It includes the installation of Liquid Film Aeration (LFA) to improve WWTP's power consumption efficiency.

2 DESIGN AND METHODOLOGY

In collaboration with Earth Creative Co., Ltd., this study developed the IoT-based real-time monitoring system and the Liquid Film Aeration (LFA) to monitor and improve power consumption efficiency. The field surveys and data collection of WWTP were conducted first to create an appropriate design for the IoT system. After analyzing the surveyed and collected data from WWTP, the design of the IoT system is decided, as shown in Figure 1. This IoT system consists of pH, DO, and temperature sensors installed on the inlet, aeration, and outlet tank (the DO sensor is only installed in the aeration tank). The LFA is also installed to improve the aeration processes in Aeration Tank.

The pH, DO, and temperature data are collected by each sensor and then processed by the microcontroller unit (MCU). The processed data or information in MCU is then transferred to the Main Controller Unit, as shown in Figure 2, through a wired connection. The information of the Main Controller Unit is transferred to the web-based data center by wireless connection. Furthermore, authorized users can access the information via the website-based user interface. The database of this website is managed by Earth Creative Co., Ltd. The officers of Udayana University Hospital have full access to this system to support their jobs in monitoring and managing WWTP.

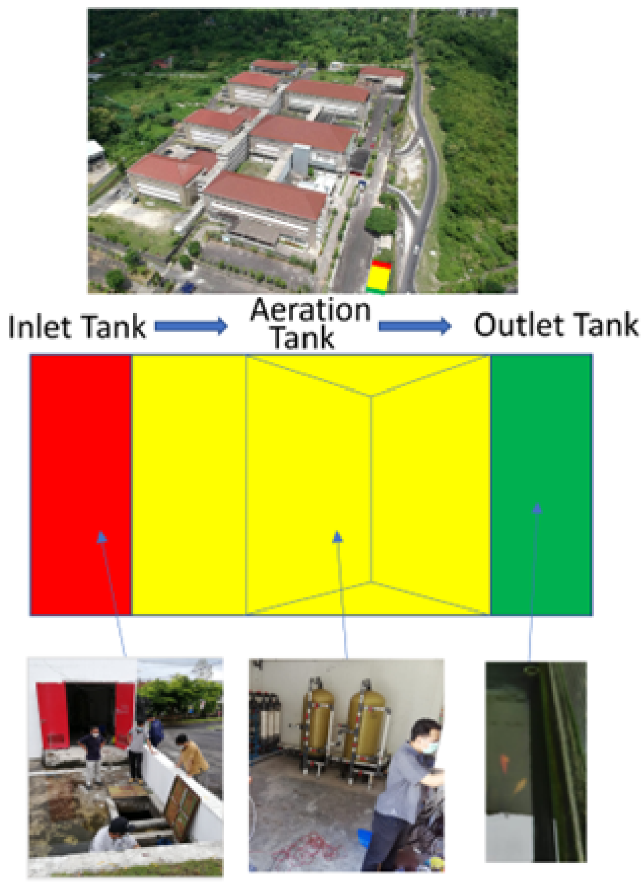

Figure 4 Simplified sitemap of WWTP in Udayana University Hospital

3 SYSTEM IMPLEMENTATION, PERFORMANCE RESULTS, AND DISCUSSION

3.1 Installation of IoT-based Real-time Monitoring System

Figure 3 shows the location of WWTP in Udayana University Hospital, which is the Northern part of Udayana University Hospital. The sitemap of WWTP in Udayana University Hospital is shown in Figure 4. It is operated nonstop (24 hours a day), and it consists of Inlet (red color), Aeration (yellow color), and Outlet Tank (green color). The type used in Udayana University Hospital WWTP is an activated sludge with a 150 m^3 day^{-1}capacity.

Figure 5 shows the position of each sensor and LFA. pH and Temperature sensors are installed in the Inlet and Outlet Tank, while pH, Temperature, DO sensors, and two units of LFA are installed in the aeration tank. In general, each sensor from the tank collects the data and sends the information to the control box by a wired connection. The control box processes the collected data and sends the processed information to the data server by wireless connection.

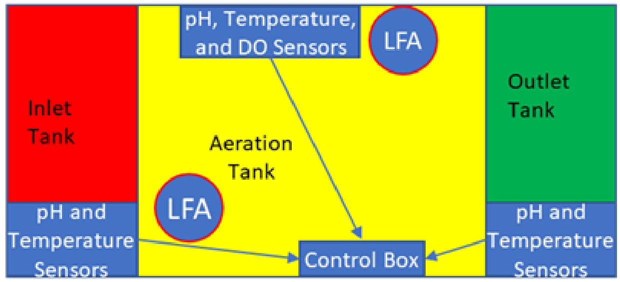

Figure 5 Sensors and LFA position in WWTP Udayana University Hospital

Figure 6 shows the installation of an IoT-based real-time monitoring system at Udayana University Hospital. As mentioned in "Design and Methodology", this IoT consists of three main sensors, namely, pH, temperature, and DO sensors, as shown in Figures 6(a), 6(b), and 6(c), respectively.

The combination of those three sensors, namely pH, temperature, and DO, in a single floating case is shown in Figure 6 (d). All three sensors are connected to a microcontroller, as shown in Figure 6(e). This microcontroller receives data from each sensor and transmits the pH, temperature, and DO information to the main control box (Figure 6(f)). Each tank has one microcontroller, and the main controller sends the information from each tank to the web server.

The users or officers can access the monitoring results in a web-based user interface. This system is very effective compared with conventional or direct measurement. It reduces direct contact among officers on the site and minimizes the infection risk to the officers.

3.2 Installation of LFA

The installation of LFA aims to improve power consumption efficiency in the aeration process. Figures 7(a) and 7(b) show the LFA before and after being installed into the Aeration Tank. This LFA replaces the conventional root blower, which consumes much more electricity than LFA. The effect of LFA installation is presented in the next section. This LFA combines two-unit air pumps (Yasunaga type L240 air pump).

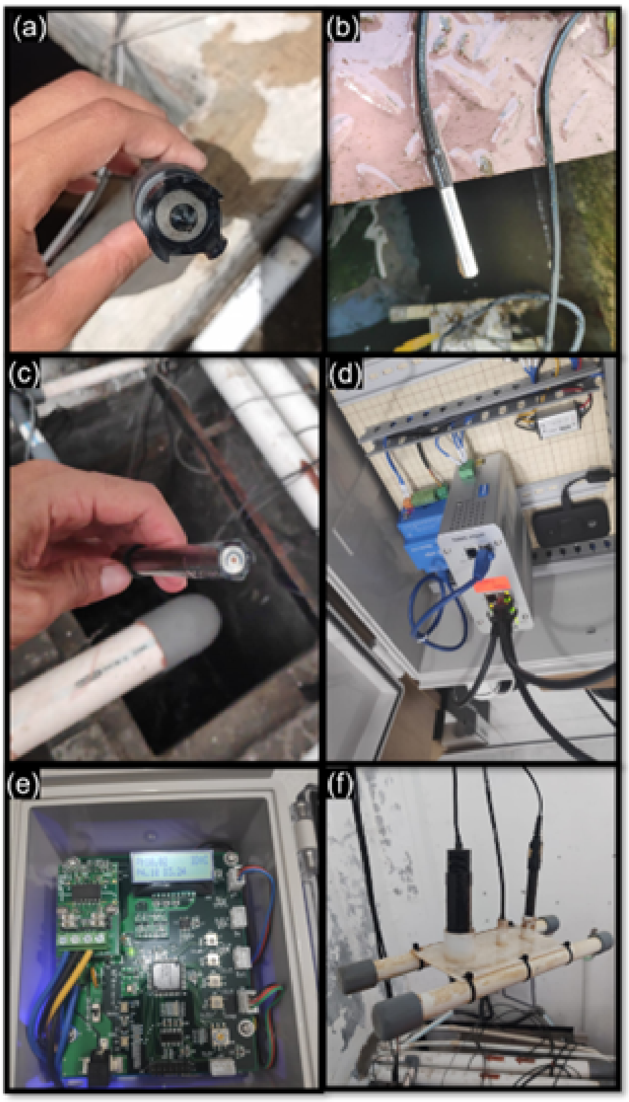

Figure 6 Installation of IoT-based real-time monitoring system; (a) pH sensor, (b) temperature sensor, (c) DO sensor, (d) installation of three sensors (pH, temperature, and DO sensors), (e) microcontroller, and (f) main controller

3.3 Monitoring Results in The Website-based User Interface

The monitoring result is presented as a real-time web-based user interface, as shown in Figure 8. Furthermore, the information about pH and temperature in Inlet and Outlet Tanks, as well as pH, temperature, and DO in the Aeration Tank, are shown in Figure 8. The users or officers can analyze this information from their office or everywhere as long as they have devices (smartphones, tablets, or laptops) connected to the internet network. As long as the monitoring results (pH, temperature, and DO) are under the permitted limit, the users or officers are not required to visit the WWTP site. This condition increases efficiency in manpower usage and keeps the officers from COVID-19 infection.

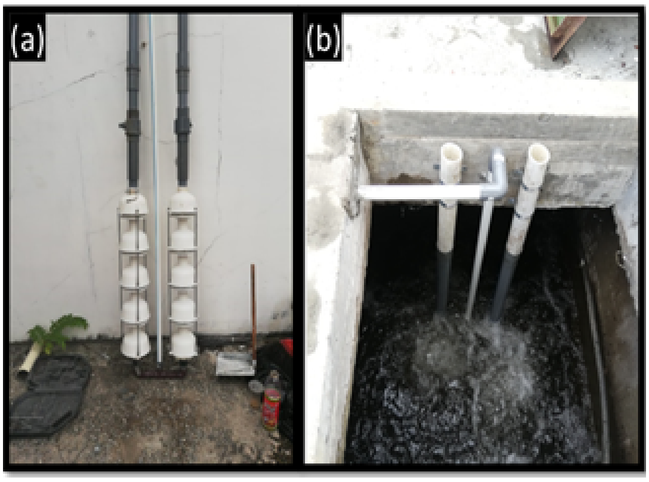

Figure 7 Installation of LFA; (a) LFA unit before installation, and (b) Installed LFA

In a case where one or more parameters exceed their limits, the decision or action should be taken by officers according to the statistical analysis of monitored data. In the worst case, the officers may require visiting the WWTP site directly.

Table 1 shows the comparison of conventional aeration and LFA. Conventional aeration using a root blower with a power input of 1500 watts has the highest obtained DO of 2.42. After replacing the root blower with a Yasunaga-type L240 air pump and a total input power of 500 watts (250 watts for each pump), the highest obtained DO is 1.42. Finally, using a two-unit air pump, Yasunaga type L240 coupled with the LFA obtained the highest DO of 1.83.

Table 1 shows that the DO value obtained by conventional aeration with a root blower is higher than LFA. However, a simple efficiency calculation, such as DO/total power consumption, shows that LFA has better power usage efficiency. Conventional aeration with a root blower requires 619.8 watts to produce 1 mg L^{-1} of DO, while LFA only requires only 273.2 watts.

3.4 Maintenance of IoT-based Real-time Monitoring System

Maintenance works are very important to keep the IoT-based real-time monitoring system at its best performance. Based on the experiences in WWTP

Table 1. Comparison of conventional aeration and LFA

Parameters	Conventional aeration with root blower air pump	Conventional aeration with Yasunaga type L240 air pump	LFA + Yasunaga type L240 air pump
DO	2.42 mg L^{-1}	1.42 mg L^{-1}	1.83 mg L^{-1}
Power consumption	1500 watts	500 watts	500 watts
Power consumption to produce 1 mg L^{-1} of DO	619.8 watts	351.2 watts	273.2 watts

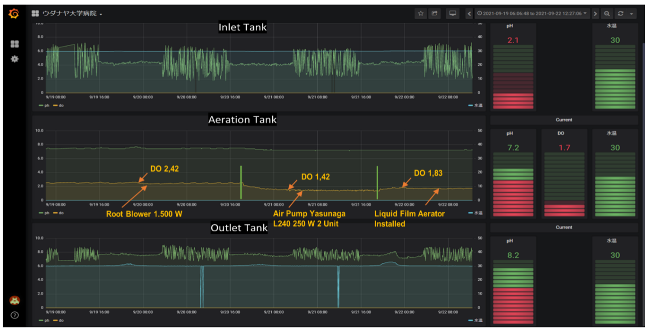

Figure 8 The monitoring results IoT based real-time monitoring system presented in web-based user interface and the effect of LFA installation in the Aeration Tank

in Udayana University Hospital, three main points need special attention, namely:

(a) Sensor cleanness
(b) Stability of electric power supply to the IoT system
(c) Stability of internet connection

Figure 9 shows the condition of the pH sensor in Outlet Thank after a few months of usage. It revealed some dirty parts in the main component of the pH sensor. This condition can reduce the accuracy of the sensor and may give inaccurate measured data. In this situation, a periodic cleaning process for all sensors is essential, at least once a month.

IoT monitoring systems mostly utilize electrical devices that are very sensitive to the electric power supply. In this study, when the electric power supply suddenly decreases, the IoT monitoring system restarts automatically, thereby temporarily losing some monitoring results. Moreover, the IoT monitoring system is useless without a stable internet connection. It does not require a special high-bandwidth internet connection due to the very

Figure 9 pH sensor condition after a few months of installation

small size of the transmitted file. The most important is a stable internet connection (never disconnected).

4 CONCLUSION

The IoT-based real-time monitoring system and LFA are developed and applied to the Wastewater Treatment Plan (WWTP) site in Udayana University Hospital. This system is proven very effective in reducing human contact at the WWTP site, and it also minimizes the risk of Covid-19 virus transmission to hospital officers. Regarding the installation of LFA, it is found to show better power usage efficiency than conventional aeration. Furthermore, conventional aeration with a root blower requires 619.8 watts to produce 1 mgL^{-1} of DO, while LFA only requires 273.2 watts. The maintenance points of this IoT-based real-time monitoring system are sensor cleanness, stability of electric power supply, and internet connection. The IoT-based real-time monitoring system was successfully applied in Udayana University Hospital and is useful in other types of WWTPs, different from hospitals.

DISCLAIMER

The authors declare no conflict of interest.

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REFERENCES

Anh Khoa, T., Phuc, C. H., Lam, P. D., Nhu, L. M. B., Trong, N. M., Phuong, N. T. H., Dung, N. V., Tan-Y, N., Nguyen, H. N. and Duc, D. N. M. (2020), 'Waste Management System Using IoT-based Machine Learning in University', *Wireless Communications and Mobile Computing* **2020**, 1–13.

Arora, J., Pandya, U., Shah, S. and Doshi, N. (2019), 'Survey-pollution Monitoring Using IoT', *Procedia Computer Science* **155**, 710–715.

Bria, A., Cerro, G., Ferdinandi, M., Marrocco, C. and Molinara, M. (2020), 'An IoT-ready Solution for Automated Recognition of Water Contaminants', *Pattern Recognition Letters* **135**, 188–195.

Guo, X. (2021), 'Application of Agricultural IoT Technology Based on 5G Network and FPGA', *Microprocessors and Microsystems* **80**, 103597.

Hajjaji, Y., Boulila, W., Farah, I. R., Romdhani, I. and Hussain, A. (2021), 'Big Data and IoT-based Applications in Smart Environments: A Systematic Review', *Computer Science Review* **39**, 100318.

Hongprasith, N., Imai, T. and Painmanakul, P. (2017), 'Study of the Liquid-film-forming Apparatus as an Alternative Aeration System: Design Criteria and Operating Condition', *Environmental Technology* **38**(12), 1539–1547.

Kumar, P. M. and Hong, C. S. (2022), 'Internet of Things for Secure Surveillance for Sewage Wastewater Treatment Systems', *Environmental Research* **203**, 111899.

Lynn, T., Endo, P. T., Ribeiro, A. M. N., Barbosa, G. B. and Rosati, P. (2020), 'The Internet of Things: Definitions, Key Concepts, and Reference Architectures', *The Cloud-To-Thing Continuum: Opportunities and Challenges in Cloud, Fog and Edge Computing* pp. 1–22.

Muliarta, I. N. (2016), 'Medical Waste and its Management at Wangaya Hospital in Denpasar', *International Research Journal of Management, IT and Social Sciences* **3**(5), 94–102.

Oberascher, M., Kinzel, C., Kastlunger, U., Kleidorfer, M., Zingerle, C., Rauch, W. and Sitzenfrei, R. (2021), 'Integrated Urban Water Management with Micro Storages Developed as an IoT-based Solution–The Smart Rain Barrel', *Environmental Modelling & Software* **139**, 105028.

Pulicharla, R., Kaur, G. and Brar, S. K. (2021), 'A Year into the COVID-19 Pandemic: Rethinking of Wastewater Monitoring as a Preemptive Approach', *Journal of Environmental Chemical Engineering* **9**(5), 106063.

Rajalashmi, K., Yugathian, N., Monisha, S. and Jeevitha, N. (2021), 'IoT Based Water Quality Management System', *Materials Today: Proceedings* **45**, 512–515.

Sutrisno, H. and Meilasari, F. (2020), 'Medical Waste Management For Covid19', *Jurnal Kesehatan Lingkungan* **12**, 104–120.

Tanasiev, V., Pătru, G. C., Rosner, D., Sava, G., Necula, H. and Badea, A. (2021), 'Enhancing Environmental and Energy Monitoring of Residential Buildings Through IoT', *Automation in Construction* **126**, 103662.

Ullah, H., Ullah, A., Gul, A., Mousavi, T. and Khan, M. (2021), 'Novel Coronavirus 2019 (COVID-19) Pandemic Outbreak: A Comprehensive Review of The Current Literature', *Vacunas (English Edition)* **22**(2), 106–113.

Vasudevan, S. K. and Baskaran, B. (2021), 'An Improved Real-time Water Quality Monitoring Embedded System with IoT on Unmanned Surface Vehicle', *Ecological Informatics* **65**, 101421.

Wen, Z., Hu, S., De Clercq, D., Beck, M. B., Zhang, H., Zhang, H., Fei, F. and Liu, J. (2018), 'Design, Implementation, and Evaluation of an Internet of Things (IoT) Network System for Restaurant Food Waste Management', *Waste management* **73**, 26–38.

Yuniti, D. I., Sasmita, N., Komara, L. L., Purba, J. H. and Pandawani, N. P. (2020), 'The Impact of Covid-19 on Community Life in The Province of Bali, Indonesia', *International Journal of Psychosocial Rehabilitation* **24**(10), 1918–1929.

Zhu, H., Imai, T., Tani, K., Ukita, M., Sekine, M., Higuchi, T. and Zhang, Z. (2007*a*), 'Enhancement of Oxygen Transfer Efficiency in Diffused Aeration Systems Using Liquid-film-forming Apparatus', *Environmental technology* **28**(5), 511–519.

Zhu, H., Imai, T., Tani, K., Ukita, M., Sekine, M., Higuchi, T. and Zhang, Z. (2007*b*), 'Improvement of Oxygen Transfer Efficiency in Aerated Ponds Using Liquid-film-Assisted Approach', *Water science and technology* **55**(11), 183–191.

Široka, M., Piličić, S., Milošević, T., Lacalle, I. and Traven, L. (2021), 'A Novel Approach for Assessing the Ports' Environmental Impacts in Real Time – The IoT Based Port Environmental Index', *Ecological Indicators* **10**(1016), 120.