Promoting Industry 4.0 Awareness through the Implementation of an IoT-Based Wastewater Monitoring System in Yogyakarta's Hotel Industry

Muhammad Fatih Qodri[1]*, Bagus Gilang Pratama[2], Okki Verdiansyah[1], Irvan Ardhi Permana[2], Nodyka Elkawi Hawinu[1]

[1]Geological Engineering Department, Faculty of Engineering and Planning, Institut Teknologi Nasional Yogyakarta, Yogyakarta, Indonesia

[2]Electrical Engineering Department, Faculty of Engineering and Planning, Institut Teknologi Nasional Yogyakarta, Yogyakarta, Indonesia

Abstract The advent of Industry 4.0 has enabled the integration of digital technologies, such as the Internet of Things (IoT), across a range of sectors including the hotel industry. However, awareness and adoption of these technologies remain limited. This study aimed to promote Industry 4.0 awareness by implementing an IoT-based wastewater monitoring system in Yogyakarta's hotel sector. Conducted as a community service initiative, the system was designed and developed using sensors and an ESP32 microcontroller to monitor wastewater quality in real time. The program included an awareness campaign, technical training, system deployment, and post-implementation evaluation. The system measured key parameters including Total Dissolved Solids (TDS), pH, ammonia (NH_3), temperature, turbidity, dissolved oxygen (DO), and electrical conductivity (EC), and issued alerts when values exceeded environmental thresholds. The results showed that the system significantly improved the accuracy and responsiveness of wastewater monitoring, thereby enhancing environmental compliance and supporting sustainable tourism practices. This initiative demonstrates how modern technological adoption can be effectively aligned with sustainability goals in the hospitality industry.

1. INTRODUCTION

Tourism is one of the sectors that significantly contributes to regional economic growth and development (Wibowo et al., 2017). Yogyakarta, one of Indonesia's premier tourist destinations, attracts visitors from both domestic and international markets. With its rich cultural heritage, historical landmarks, and vibrant local life, the city experiences a consistent influx of tourists throughout the year. However, this growth also brings the responsibility of ensuring that the hospitality industry supports sustainable development (Fadhil & Zaenuri, 2021). The hospitality sector plays a vital role in the expansion of tourism. Economically, it contributes to increased revenue for local communities, including the city of Yogyakarta. The surge in tourism has been accompanied by a steady rise in the number of hotels and other types of accommodation, as shown in Table 1. These establishments play a significant role in generating employment, income, and broader local development. Nevertheless, the rapid proliferation of hotels has intensified competition, with each establishment seeking to improve services, facilities, and pricing to attract more guests. In this competitive landscape, hotels often prioritize guest satisfaction and financial gain, while overlooking the environmental impacts of their operations (Bardukova, 2023; Singgalen, 2024; Yakup, 2019).

One of the most pressing issues in the hospitality sector is the inadequate management of wastewater. The rapid expansion of the hotel industry has led to a substantial increase in wastewater production, which, if not properly

Table **1** . Growth in the number of hotels in Yogyakarta by types, 2020–2024 (Dinas Pariwisata DIY, 2024)

Hotel Type	Year				
	2020	2021	2022	2023	2024
Five-Star Hotels	11	11	15	12	12
Four-Star Hotels	42	45	31	43	43
Three-Star Hotels	68	69	67	81	81
Two-Star Hotels	33	30	44	35	35
One-Star Hotels	18	17	11	16	16
Non-Star Hotels	618	1,661	1,528	1,737	1,737
Total	790	1,833	1,696	1,924	1,924

treated, can result in serious environmental and public health consequences (Hamsal & Abdinagoro, 2021; Isrososiawan et al., 2020). Wastewater generated by hotels typically contains a range of pollutants, including suspended solids, surfactants such as soaps and detergents, oils, fats, alkalinity, chloride, nitrogen, phosphorus, sulfur, and ammonia (Khajvand et al., 2022; Kurnia et al., 2020). Without effective treatment, these contaminants can exceed environmental thresholds, contributing to water pollution and damaging surrounding ecosystems (Rajak et al., 2024). In addition, untreated or insufficiently treated wastewater poses risks to human health, particularly in densely populated urban areas such as Yogyakarta. As a result, effective wastewater management is not only a legal obligation but also an essential component of sustainable tourism practices. Although the Indonesian government has established regulatory standards for wastewater discharge, many hotels continue to face challenges in meeting these requirements. This shortfall is largely attributed to a lack of adequate infrastructure and real-time monitoring systems capable of assessing wastewater quality on a continuous basis (Kementerian Lingkungan Hidup dan Kehutanan, 2016).

This community engagement project seeks to address the challenges of wastewater management in the hospitality sector by introducing an innovative solution based on Industry 4.0 technologies. Specifically, it focuses on the implementation of an Internet of Things (IoT)-based system to monitor the quality of wastewater generated by hotels in Yogyakarta. IoT technology enables the collection of real-time data, which enhances the accuracy and responsiveness of wastewater monitoring (Sharma et al., 2024; Zhang et al., 2020). This allows hotels to take prompt corrective measures when discharged wastewater fails to meet environmental standards. The system supports continuous monitoring of key parameters, including chemical composition, pollutant concentrations, and pH levels, thereby ensuring compliance with environmental regulations.

The primary objective of this initiative is to raise awareness within the hospitality industry regarding the potential of Industry 4.0 technologies in advancing sustainable development goals, particularly those related to environmental protection. By incorporating IoT-based monitoring into hotel operations, the project aims to reduce the ecological footprint of the tourism sector and promote sustainability within Yogyakarta's hotel industry. The implementation will be carried out in collaboration with one of the hotels affiliated with the Yogyakarta branch of the Indonesian Hotel and Restaurant Association (PHRI), serving as a model for broader adoption across the region.

2. METHOD

The project team conducted an in-depth investigation into wastewater management practices within the hospitality sector, with the goal of identifying key challenges that hinder the implementation of sustainable solutions. Based on these findings, a structured community engagement program was developed and implemented. The steps of the program are outlined as follows.

2.1 Awareness campaign

The first phase focused on identifying stakeholder needs and conducting an awareness campaign to support the development of a wastewater monitoring system. This campaign aimed to increase awareness among members of the Indonesian Hotel and Restaurant Association (PHRI) regarding the importance of monitoring the quality of wastewater generated by hotel operations. The initiative served as a foundation for promoting environmentally responsible practices within the hospitality industry. Through this campaign, the project sought to enhance participants' understanding of how Industry 4.0 technologies, particularly the Internet of Things (IoT), can be utilized to support sustainable and efficient wastewater management.

Table **2** . Wastewater quality standards for hotel industry (Peraturan Daerah DIY, 2016)

Parameter	Most Content (mg/L)	Most Pollution Burden (Kg/Ton)
BOD_5	28	7.0
COD	50	12.5
TSS	50	120
TDS	2,000	500
pH	6.0 – 9.0	
Oil and Total Fat	5	1.25
Coliform Bacteria		
MBAS	3	0.75
Ammonia (NH_3 - N)	10	2.5
Temperature	± 3° to air Temperature	
Most waste discharge (m^3/Ton Batik Product)	250	

2.2 System development and training

Following the identification of system requirements, the team proceeded with the design and development of an integrated IoT-based wastewater monitoring system.

This system employs sensors connected to the Internet to monitor wastewater quality and ensure compliance with regulatory standards established by the government (Table 2).

a   The IoT-based wastewater monitoring system represents a modern technological approach to effective wastewater management. The system includes sensors for measuring Total Dissolved Solids (TDS), pH, ammonia (NH_3), temperature, turbidity, dissolved oxygen (DO), and electrical conductivity (EC) or oxidation-reduction potential (ORP), as illustrated in Figure 1. The detailed specifications of each sensor are presented in Table 3. These integrated sensors continuously collect data, which is transmitted via the Internet, enabling real-time monitoring of wastewater conditions within the hotel partner's premises.

Figure **1** . Integrated sensors for waterwaste monitoring

b   The system is built around the ESP32 microcontroller, which reads wastewater quality data using multiple sensors. The values collected by the ESP32 are compared to predefined thresholds set by the user. If the readings for parameters such as Total Dissolved Solids (TDS) or pH exceed these limits, the system triggers an audible alert (Qodri et al., 2024). In addition, the sensor data are transmitted to the user's smartphone, enabling real-time monitoring of wastewater quality. To ensure efficient communication, the system utilizes an MQTT server as the data terminal and intermediary between the ESP32 and the smartphone, facilitating seamless data transmission. The overall workflow of the wastewater monitoring system is presented in Figure 2. The system performs continuous monitoring of all installed sensors. When measurements exceed the defined thresholds—such as TDS levels above 2000 ppm, pH values below 6 or above 9, or ammonia concentrations greater than 10 ppm—an alert is triggered via a buzzer, and a corresponding notification is sent to the operator's smartphone. As long as the device remains connected to the Internet, the operator can track key wastewater quality parameters, including TDS, pH, temperature, and ammonia, in real time.

2.3 Technology implementation

The next phase involves implementing the system within the hotel industry, with adaptations tailored to the specific conditions and operational environments of the partner hotels. This stage includes a series of trials and evaluations to ensure that the system functions effectively and meets user requirements. Testing under real-world conditions will be conducted to validate the system's performance, reliability, and suitability for application in the hospitality sector.

2.4 Training and evaluation

Following system deployment, training sessions will be provided for end users, primarily hotel staff and members of the Indonesian Hotel and Restaurant Association (PHRI) Yogyakarta Chapter (PHRI DIY). The training is intended to enhance users' understanding of the system, ensuring they are equipped to operate it accurately and independently. In addition to training, continuous evaluation will be conducted to assess the effectiveness of the IoT-based wastewater monitoring system. This evaluation will focus on the extent to which the system contributes to sustainable tourism practices by improving wastewater management among PHRI DIY member hotels.

2.5 Program sustainability

To ensure long-term sustainability, the outcomes of this project will be disseminated to all PHRI members and shared through academic journals and other media platforms. The broader objective is to encourage the adoption of this technological innovation across the hotel industry in Yogyakarta. By the year 2030, the project envisions permanent installation and operation of the

Table **3** . List of sensors and their functions in wastewater monitoring system

| Parameter	Sensor/Module	Paraphrased Function Description
Ammonia Gas	Ion-Selective Electrode (ISE) or MQ-135	Detects the concentration of ammonia gas, which is a key indicator of organic pollution.
Electrical Conductivity (eC)	Gravity Analog Electrical Conductivity	Detects the ability of water to conduct electricity, often linked to the concentration of dissolved salts (TDS).
Dissolved Oxygen	Gravity Analog Dissolved Oxygen	Measures the oxygen content in water, crucial for evaluating the water's suitability for aquatic life.
Temperature	DFRobot DS18B20	Records the water temperature, which influences chemical reactions and biological activity.
Turbidity	DFRobot Non-Contact Turbidity Sensor	Assesses water clarity by measuring the scattering of light caused by suspended particles.
pH	Seeed Studio Industrial pH Meter	Provides precise measurements of pH levels for industrial-grade water quality assessments.
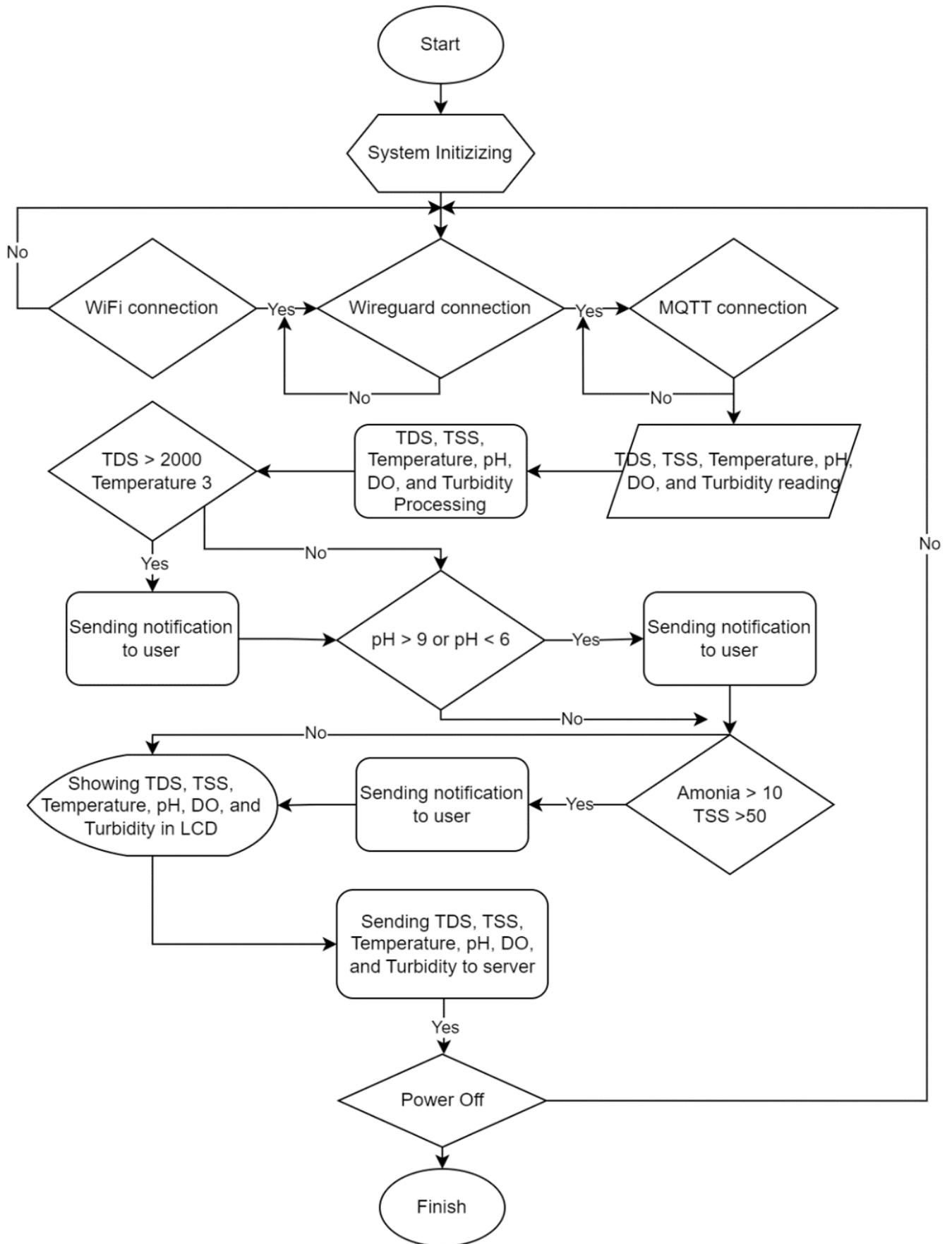
Figure 2 . System flow diagram

system in at least ten hotels. Through this initiative, the hospitality sector is expected to become more environmentally responsible, thereby contributing to the long-term sustainability of tourism in the region.

3. RESULT AND DISCUSSION

The implementation of the Internet of Things (IoT)-based wastewater monitoring system provides a practical and innovative solution for enhancing environmental monitoring within the hotel industry. This program was designed not only to introduce Industry 4.0 technologies but also to promote sustainable tourism practices through improved wastewater management.

3.1 Awareness about Industry 4.0 and IoT-based wastewater measurement tools

The awareness campaign began with a series of coordinated promotional activities, delivered through both online webinars and in-person stakeholder meetings. A key event took place on September 19, 2024, during which a faculty team from the Institut Teknologi Nasional Yogyakarta (ITNY) met with representatives of the Indonesian Hotel and Restaurant Association, Regional Board of Yogyakarta (PHRI BPD DIY). At this meeting, the concept of IoT-based wastewater monitoring systems was formally introduced to hotel industry stakeholders (Figure 3).

Figure 3 . Industry 4.0 promotion and awareness session

During the session, Mr. Deddy Pranowo Eryono, Chairman of PHRI BPD DIY, officially received the monitoring tools for pilot implementation. This event was followed by ongoing dissemination efforts and interactive discussions designed to deepen stakeholder understanding of Industry 4.0 technologies and their application in sustainable hospitality operations.

In addition to the awareness campaign, a questionnaire was distributed to 30 participating hotels to assess their perceptions of the program. The summarized responses are presented in Figure 4.

The majority of hotel representatives strongly agreed with the usefulness and relevance of the IoT-based wastewater quality monitoring system. This positive response reflects a high level of interest and support for

technological innovation in promoting sustainable tourism practices. Approximately 30 percent of participants indicated agreement, suggesting a generally favorable outlook, albeit with potential reservations. These reservations may pertain to the need for further clarification, practical demonstrations, or assurance regarding the system's integration into existing hotel operations. Meanwhile, 10 percent of respondents expressed a neutral stance or uncertainty. This response may reflect limited understanding of the technology, concerns about implementation challenges, or a cautious attitude regarding the system's long-term effectiveness and cost-efficiency (Bardukova, 2023). Notably, no participants expressed disagreement, which highlights a general openness and readiness for future adoption within the local hotel industry.
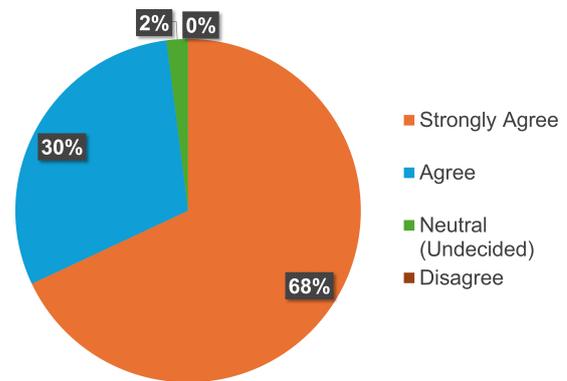

Figure 4 . Perceptions of the program among 30 participating hotels

3.2 Technological products and innovations

The project successfully developed an integrated IoT-based system that combines both hardware and software components. The system is built around an ESP32 microcontroller connected to six sensors that operate continuously to monitor wastewater quality. Each sensor probe was clearly labeled to facilitate accurate installation, as shown in Figure 5. It is important to note that the sensors used for oxidation-reduction potential (ORP), dissolved oxygen (DO), and electrical conductivity (EC) share similar physical structures. Improper installation may lead to inaccurate readings or damage to the sensor modules. The same caution applies to the turbidity and temperature probes, which require precise port alignment (Qodri et al., 2024).

Prior to initiating any measurements, users must ensure that each labeled probe is correctly installed in its designated port. Incorrect connections can result in faulty data output or sensor malfunction. Once operational, the data collected by the sensors are processed and analyzed by the ESP32 microcontroller. If any parameter exceeds the predefined thresholds—such as pH values below 6 or above 9, total dissolved solids (TDS) greater than 2000 ppm, or ammonia levels exceeding 10 ppm—the system triggers an audible buzzer and transmits an alert via MQTT to a cloud-based platform. This platform is accessible through

both local device displays and remote smartphone or web dashboards, as illustrated in Figure 6 and Figure 7.
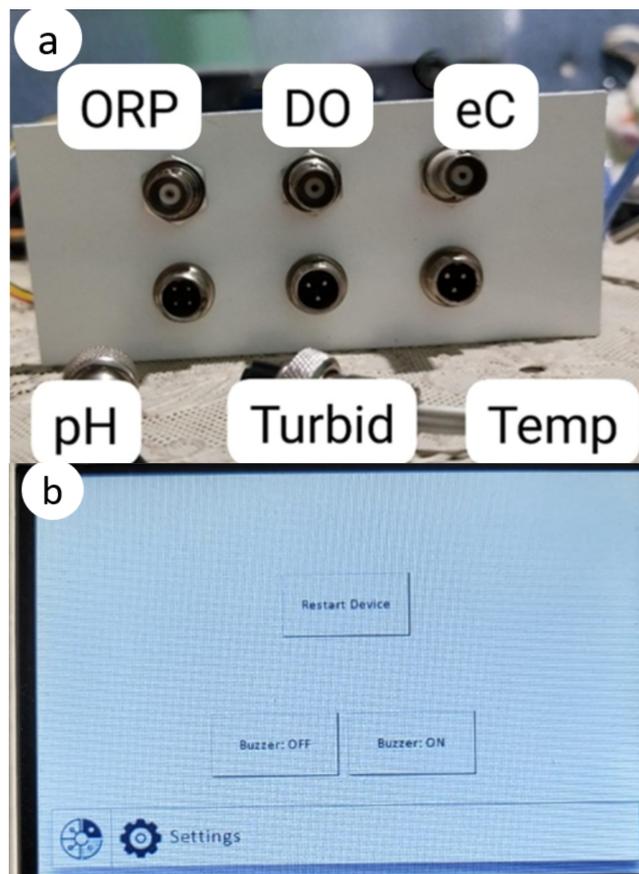

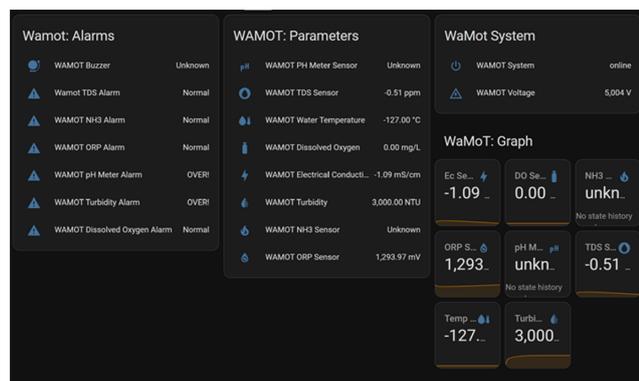Figure 5 . a) Probe setup & b) Sensor configuration before measurement

Figure 6 . User interface on smartphone or web-based dashboard

The system's software enables real-time data visualization, trend analysis, and automatic notifications, thereby enhancing operational efficiency and supporting informed decision-making. These features allow hotel staff to monitor wastewater conditions continuously and respond promptly to any irregularities. To ensure effective implementation, hotel technicians and environmental personnel participated in a series of technical training sessions (Figure 8). The training covered both the operational aspects of the system and

the basic interpretation of monitoring data. This approach was intended to build technical capacity and promote autonomous system management within the hotels.
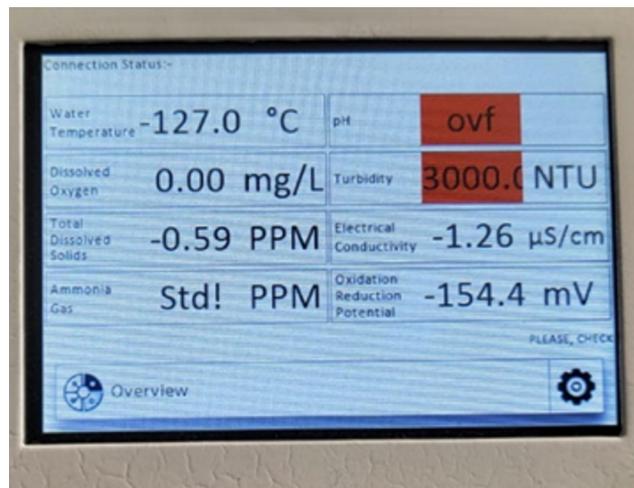

Figure 7 . On-field screen display from IoT-based wastewater monitoring device

Figure 8 . Training and trial session on the IoT-based wastewater monitoring system

3.3 Technology implementation

The prototype system was installed at a partner hotel in Yogyakarta that demonstrated a strong commitment to sustainable tourism and Industry 4.0 integration (Figure 9). The hotel management actively participated in the installation process and expressed a keen interest in incorporating the monitoring tool into their regular environmental management routines. Several challenges emerged during the implementation phase. These included difficulties in initial sensor calibration due to variability in wastewater composition, occasional instability in Internet connectivity that affected MQTT-based data transmission, and the need to reposition certain probes to minimize interference from sediment accumulation (Qodri et al., 2024).

The primary outcome of this initiative was the successful development and deployment of a complete IoT-based wastewater monitoring system, consisting of both hardware and software components as reviewed in Table 4. The hardware included six sensor probes, all of which were

tested and verified to function correctly under operational conditions.

Following the installation, the hotel management reported increased confidence in their ability to monitor and respond to potential wastewater pollution risks. In addition, nearby communities benefited from reduced exposure to environmental hazards associated with untreated or poorly managed wastewater discharge.

Figure **9** . Installation of IoT wastewater monitoring tool in a hotel wastewater treatment system

Table **4** . Functionality status of IoT-based wastewater monitoring sensors

Sensor Type	Functionality Status
Total Dissolved Solids (TDS)	Working
pH Sensor	Working
Ammonia (NH$_3$)	Working
Temperature	Working
Turbidity	Working
Electrical Conductivity (EC) / ORP	Working

3.4 Impact and productivity

The adoption of the IoT-based automatic wastewater monitoring system in hotel wastewater management is expected to yield positive impacts. Most notably, the environmental quality surrounding the hotels is anticipated to improve, particularly through the availability of cleaner and safer water sources. In addition, the automation of wastewater monitoring has streamlined hotel operations by reducing management costs and enabling quicker responses to potential quality issues. This proactive approach to environmental management has also enhanced tourists' confidence in the hotels' commitment to sustainability. As a result, participating hotels have strengthened their competitiveness in Yogyakarta's increasingly environmentally conscious tourism market.

4. CONCLUSION

This engagement project demonstrates that the implementation of an IoT-based wastewater monitoring system in Yogyakarta's hotel industry has significantly enhanced environmental management practices. Through a combination of technical training and awareness-building initiatives, hotel staff have acquired the knowledge and skills necessary to operate the system effectively, fostering a proactive and informed approach to wastewater monitoring.

The integration of real-time data collection and automated alert mechanisms has improved response times to potential water quality issues, thereby reducing the risk of environmental pollution. The findings underscore the value of collaboration between academic institutions and industry stakeholders in advancing innovative solutions to address contemporary environmental challenges.

Moreover, this community engagement initiative contributes meaningfully to the broader objectives of sustainable tourism in Yogyakarta, positioning the region as a frontrunner in environmentally responsible hospitality. The success of this program highlights the potential for replicating similar IoT-based interventions in other sectors, reinforcing the pivotal role of digital technologies in promoting sustainability and advancing Industry 4.0 goals. Looking ahead, sustained engagement and support from hotel operators and staff will be essential to ensure the long-term impact and scalability of this initiative.

CONFLICT OF INTERESTS

The authors declare that there are no conflicts of interest related to this project.

REFERENCES

Bardukova, L. (2023). Navigating the hospitality horizon: Current trends and strategies for customer attraction and retention in the hotel industry. *Economics and Computer Science*, *2*, 88—103.

Dinas Pariwisata DIY. (2024). *Jumlah hotel*. Dinas Pariwisata Daerah Istimewa Yogyakarta.

Fadhil, R. M. & Zaenuri, M. (2021). Strategi recovery Dinas Pariwisata Kota Yogyakarta pada masa *new normal*. *Jurnal Pemerintahan dan Kebijakan (JPK)*, *2*(2), 60—71.

Hamsal, M. & Abdinagoro, S. B. (2021). *Sustainable tourism pariwisata wisata di era normal baru*. Scopindo Media Pustaka.

Isrososiawan, S., Rahayu, A., Wibowo, L. A., & Dewatmoko, S. (2020). *Green human resources management* mendukung kinerja lingkungan industri perhotelan. *Jurnal Co Management*, *3*(2), 457—470.

Kementerian Lingkungan Hidup dan Kehutanan. (2016). Peraturan menteri lingkungan hidup dan kehutanan nomor P.68 tahun 2016 tentang baku mutu air limbah domestik.

Khajvand, M., Mostafazadeh, A. K., Drogui, P., & Tyagi, R. D. (2022). Management of greywater: Environmental impact, treatment, resource recovery, water recycling, and decentralization. *Water Science & Technology*, *86*(5), 909—937.

Kurnia, S., Syamsinar, S., & Afdaliah, A. (2020). Akuntansi manajemen limbah industri perhotelan (studi kasus: Sebuah hotel bintang empat di Makassar). *AKUNSIKA: Jurnal Akuntansi dan Keuangan*, *1*(1), 87—101.

Peraturan Daerah DIY. (2016). Peraturan daerah DIY nomor 7 tahun 2016 tentang baku mutu air limbah.

Qodri, M. F., Pratama, B. G., Yuliani, O., & Permana, I. A. (2024). Innovative internet of things-based integrated liquid waste monitoring for sustainable batik industry. *SPEKTA (Jurnal Pengabdian Kepada Masyarakat: Teknologi dan Aplikasi)*, *5*(1), 37—50.

Rajak, P., Ganguly, A., Nanda, S., Mandi, M., Ghanty, S., Das, K., Biswas, G. & Sarkar, S. (2024). Toxic contaminants and their impacts on aquatic ecology and habitats. In *Spatial modeling of environmental pollution and ecological risk* (pp. 255—273). Woodhead Publishing.

Sharma, S., Sharma, K., & Grover, S. (2024). Real-time data analysis with smart sensors. In *Application of artificial intelligence in wastewater treatment* (pp. 127—153). Cham: Springer Nature Switzerland.

Singgalen, Y. A. (2024). Hotel customer satisfaction: A comprehensive analysis of perceived cleanliness, location, service, and value. *Journal of Business and Economics Research (JBE)*, *5*(3), 352—369.

Wibowo, S., Rusmana, O., & Zuhelfa, Z. (2017). Pengembangan ekonomi melalui sektor pariwisata tourism. *Jurnal Kepariwisataan: Destinasi, Hospitalitas dan Perjalanan*, *1*(2), 93—99.

Yakup, A. P. (2019). Pengaruh sektor pariwisata terhadap pertumbuhan ekonomi di Indonesia [Dissertation]. Universitas Airlangga.

Zhang, W., Tooker, N. B. & Mueller, A. V. (2020). Enabling wastewater treatment process automation: Leveraging innovations in real-time sensing, data analysis, and online controls. *Environmental Science: Water Research & Technology*, *6*(11), 2973—2992.