

Performance Assessment of Integrated Water Quality Monitoring Device with IoT Technology for Water Quality Monitoring

Muhammad Izz Hakimi Zaidi Farouk¹, Zadariana Jamil^{1*}, Mohd Fuad Abdul Latip², Nur Kamaliah Mustaffa¹, Azianabiha A. Halip¹, Normaliza Noordin³, Yahzam Muhamad³, Nik Norazlina Che Ya³

¹ Faculty of Civil Engineering,
Universiti Teknologi MARA, 40450 Shah Alam, Selangor, MALAYSIA

² Faculty of Electrical Engineering,
Universiti Teknologi MARA, 40450 Shah Alam, Selangor, MALAYSIA

³ Environment, Lake and Wetland Division, City Planning Department,
Putrajaya Corporation, 62675 Putrajaya, MALAYSIA

*Corresponding Author: zadariana@uitm.edu.my
DOI: <https://doi.org/10.30880/ijie.2025.17.07.009>

Article Info

Received: 20 January 2025
Accepted: 17 September 2025
Available online: 23 December 2025

Keywords

Surface water quality monitoring,
Internet of Things, prototype
deployment, smart technology,
validation

Abstract

A continuous water supply is a vital resource for domestic use and environmental sustainability, necessitating effective water management. Frequent water quality disruptions caused by river contamination have harmed aquatic life and led to shutdowns of water treatment plants, affecting consumers. The implementation of continuous online monitoring can facilitate early detection of contamination. The research focuses on the performance assessment of an integrated online water quality monitoring (IWQM) prototype (named Kolora meter) assisted with Internet of Things (IoT) technology. The IWQM prototype features seven water quality sensors, namely pH, dissolved oxygen (DO), conductivity (EC), total dissolved solids (TDS), temperature (T), turbidity (TUR), and volatile organic compound (VOC) gas, to monitor surface water. Additionally, the IWQM prototype was equipped with a mobile application, which was developed on the Blynk IoT platform. This enables the user to monitor wirelessly via smartphone or computer. This prototype was deployed and tested at Putrajaya Lake (Point 1) and Wetland (Point 2) for one month to determine its efficiency and reliability. The issues experienced during the field deployment period were identified. The data measured by the IWQM prototype was compared and validated using the data collected from a Horiba Multiparameter. The T sensor showed consistent readings with high accuracy (~0 to ~7%) while pH and DO showed inconsistent readings and accuracy. Unfortunately, the TDS, TUR, and EC could not be measured during the field deployment test due to sensor and hardware failures. The issues and mitigation strategies of the IWQM prototype have been discussed and highlighted for future improvement in the development of online water quality monitoring devices.

1. Introduction

Water contamination in rivers led to unscheduled water disruptions, which negatively affected the daily routines of people and industrial activities. One of the primary causes of water disruptions is the illegal dumping of waste into rivers by industries, which affects the water treatment facilities' inability to cope with the treatment of high amounts of contaminants, especially at water intakes [1]. Contamination of raw water by pathogens and heavy metals can lead to waterborne diseases, which have adverse effects on human health and the food chain [2]. In addition, non-point source contamination has emerged as a major global issue and remains a challenging problem to manage in water sources [3]. Hence, the quality of water intakes must be continuously monitored to detect harmful contaminants, control water contamination, prevent negative environmental effects, ensure sufficient urban water cycle management, and prevent the sudden closure of water treatment plants [4], [5].

The conventional method for water quality monitoring involves manually collecting water samples at the site and sending them to the laboratory for analysis [6], [7]. The common monitoring frequencies for the conventional method are usually on a weekly, monthly, and seasonal basis, which are relatively low [7] and ineffective for detecting pollution because they involve formulating standards for water trend sequences from particular areas. Additionally, the interval between sampling and laboratory analysis, which can be prolonged from hours to days, may lead to chemical changes in the water sample's content [8]. On the other hand, advanced laboratory techniques to assess water quality, such as inductively coupled plasma and gas chromatography, are costly and time-consuming, inefficient, expensive and unable to meet the requirements of water quality monitoring in the present day [9], [10]. These methods were time-consuming, inefficient, expensive and unable to meet the requirements of water quality monitoring in the present day [11], [12]. Therefore, online monitoring provides a real-time approach that enables faster reaction times when contamination occurs, higher data frequency, and greater adaptability. This method could also be applied in remote locations [13].

The aim of Internet of Things (IoT) implementation is to collect important data in real-time with minimal human involvement. It can be adapted to various kinds of applications, including water systems, military operations, smart homes, agriculture, infrastructure, space, transportation, and the healthcare sector [14]. The application of IoT to examine the quality of water and wastewater is essential for sustainable water resource management [2]. The integration of automated systems, such as the IoT and smart systems, can be used as a platform for continuous monitoring and water quality control [15]. The ability to detect water contamination in real-time offers immediate responses through early warning features [16]. The real-time data can help authorities to access the latest water quality information, detect potential pollution sources, and conduct emergency mitigation of water bodies. In this study, a fully functional integrated water quality monitoring (IWQM) prototype with seven sensors (temperature, turbidity, pH, dissolved oxygen, total dissolved solids, conductivity and volatile organic compounds) was developed to monitor surface water quality using IoT technology. The IWQM prototype was deployed and tested at Putrajaya Lake and Wetland. The reliability of the IWQM prototype was assessed. The challenges during deployment were identified and discussed in this study.

2. Methodology

2.1 Integrated Water Quality Monitoring (IWQM) Prototype Development

Fig. 1 shows the block diagram of the IWQM prototype system (also known as the Kolora meter) design, which consists of two microcontrollers: the Arduino Mega 2560 (main board) and the NodeMCU ESP8266 (communication board). Seven sensors were connected to the Arduino board of the prototype: pH, T, TUR, DO, TDS, EC, and VOC. A 10W (18V) solar panel was used to charge a Tianwei lead-acid 12V, 5Ah battery, which was controlled and regulated by the DFR0580 Solar Power Manager. The solar power manager provided 5V regulated power to the Arduino board. A 5V relay switch, controlled by the Arduino board, was used to supply power from the solar power manager to the sensor modules. The NodeMCU board was utilised to upload data to the Blynk IoT Platform through an internet connection. The prototype was tested in the laboratory to ensure its functional ability prior to deployment. The physical appearance of the IWQM prototype is shown in Fig. 2.

2.2 Online Software Development Using Blynk IoT Application.

The Blynk IoT platform was utilised to develop a graphical interface for the IWQM prototype's online monitoring system. The data stored in Blynk could be accessed through the Blynk App and the Blynk Dashboard. The Blynk App and Blynk Dashboard can display the uploaded data via mobile phone and web application, respectively. The stored data could be retrieved from the Blynk Cloud by generating a report in the Blynk Dashboard. The stored data was downloaded in CSV file format for further analysis.

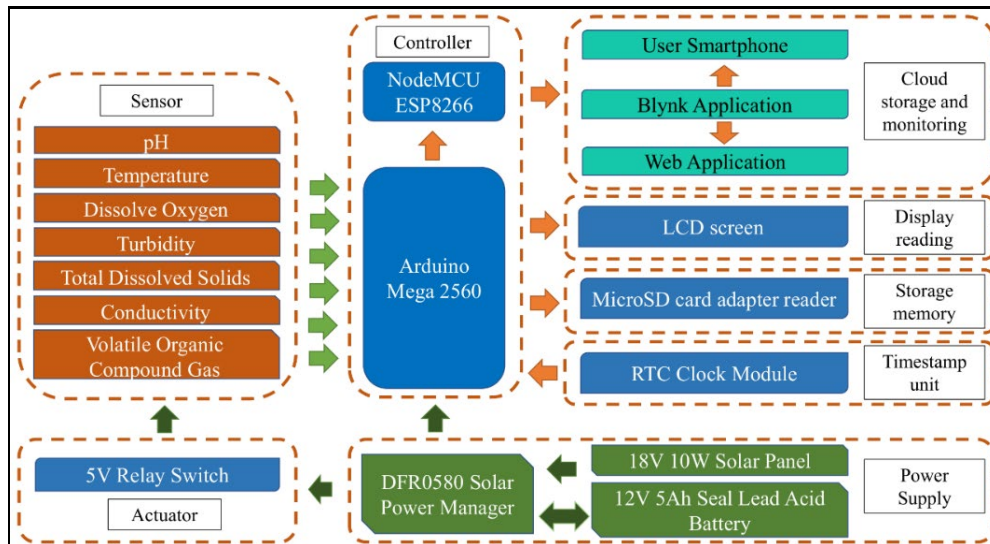


Fig. 1 The block diagram of the IWQM prototype

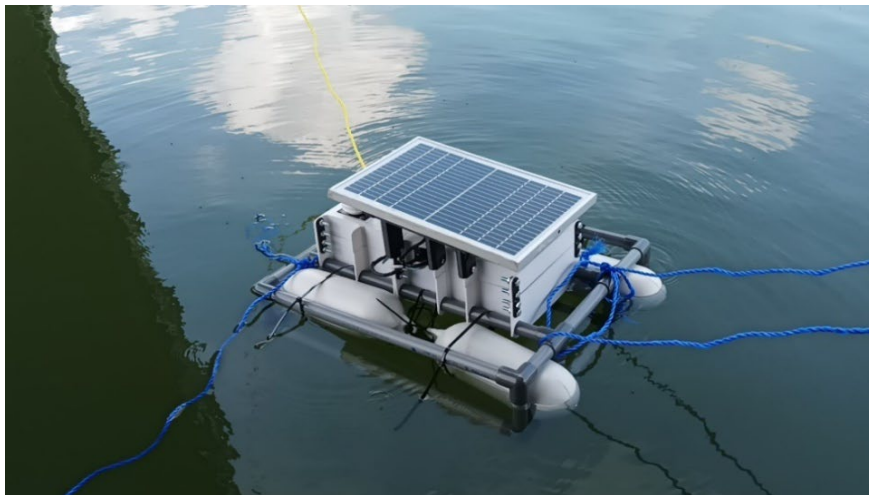


Fig. 2 The IWQM prototype during the deployment test

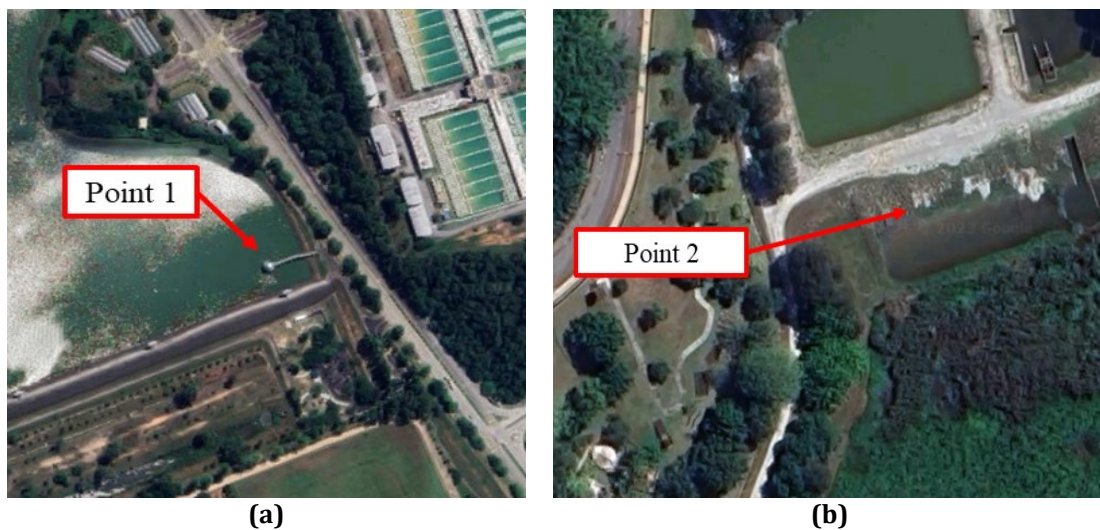


Fig. 3 The location of the IWQM prototype field deployment test at (a) Point 1, Putrajaya Lake ($2^{\circ}53'59''N$, $101^{\circ}41'10''E$); and (b) Point 2, Putrajaya Wetland ($2^{\circ}58'11''N$, $101^{\circ}41'35''E$)

2.3 Field Deployment at Putrajaya Lake and Wetland

The IWQM prototype field deployment and testing were carried out at Putrajaya Lake (Point 1, downstream) and Putrajaya Wetland (Point 2, upstream) from March 13 to May 18, 2023. The coordinates of Points 1 and 2 were at 2°53'59"N, 101°41'10"E (Fig. 3(a)) and 2°58'11"N, 101°41'35"E (Fig. 3(b)), respectively. During the IWQM prototype field deployment test, the commercial U-52G Horiba Multiparameter was used to measure water quality at the same location and time for validation purposes. Sampling and measurement were conducted twice a day, at 10:00 a.m. and 4:00 p.m., along with weather observations recorded during the field deployment test. The maintenance of the IWQM prototype was performed every two days during Week 1 until 4 to ensure measurement accuracy and sensor lifespan [17]. In Week 5, no maintenance was carried out to assess the reliability and measurement accuracy of the IWQM prototype under non-maintenance conditions.

3. Results and Discussions

3.1 IWQM Prototype Data Collection at Points 1 and 2

Table 1 presents the water quality data measured using the IWQM prototype at Points 1 and 2. The IWQM prototype was deployed for 2 weeks at each monitoring point. Proper maintenance of the IWQM prototype was conducted every 2 days, involving the cleaning of sensors and hardware, as well as checks to prevent contaminants such as sediments or suspended solids from affecting sensor readings. However, deployment in Week 5 was carried out without any maintenance, which resulted in the battery weakening and being unable to restore sufficient power from the installed solar panel unit by evening. The most common weather conditions at both places were described as clear, followed by partly cloudy and cloudy circumstances. Due to severe thunderstorms during rain and heavy rain, it is not feasible to conduct in-situ monitoring due to safety concerns.

Table 1 The duration of deployment of the IWQM prototype in Points 1 and 2

Duration	Deployment description
Week 1 (13th – 19th March 2023)	Point 1 (with maintenance)
Week 2 (22nd – 28th March 2023)	Point 1 (with maintenance)
Week 3 (5th – 12th April 2023)	Point 2 (with maintenance)
Week 4 (4th – 9th May 2023)	Point 2 (with maintenance)
Week 5 (12th – 18th May 2023)	Point 1 (without maintenance)

Fig. 4 shows the data collected from the Horiba Multiparameter and IWQM prototype at Points 1 and 2. Some data was missing because the IWQM prototype was under maintenance, and the battery was dead due to the bad weather. The IWQM prototype TUR, EC, and TDS sensors were unable to provide any readings throughout the deployment period due to hardware problems and sensor malfunctions. The IWQM prototype T sensor (Fig. 4(a)) showed the most consistent readings, with a percentage difference of 0 to ~7%, although some errors were higher on May 4 and 5, 2023, at ~10% and 14%, respectively. Approximately 12% error was measured on March 13, 2023, due to sensor fluctuations, which impacted the T values [18].

The IWQM prototype pH sensor (Fig. 4(b)) recorded an average percentage error of ~8% to 18% in Weeks 1 and 2. The IWQM prototype pH sensor in Week 3 was observed to have a constant percentage error of ~58% to 72% compared to the Horiba multiparameter readings. However, in Week 4, the percentage error exceeded 100% as the sensor measured pH 14. The issue was due to the loss of cable connection between the IWQM pH sensor module and the sensor probe, resulting the inaccurate measurement. The IWQM prototype pH sensor recorded errors in the final week (Week 5) of deployment, ranging from ~27% to 53%. This indicates that the pH sensor's efficiency deteriorated over time. This may be due to electrode fouling caused by contaminants, especially when maintenance is not performed [19]. Furthermore, frequent calibration is required to maintain accurate measurements.

The IWQM prototype DO sensor (Fig. 4(c)) exhibited a high percentage error, ranging from ~1% to 52%, and an error of up to 63% on May 18, 2023, at Point 1. At Point 2, the error ranged from ~38% to ~62%, with a higher error of ~74% on May 5, 2023. DO sensor is a critical tool for monitoring water quality, but they can be prone to various errors that affect their accuracy and reliability. The significant error of the IWQM DO sensor may be due to biofouling, caused by organisms, algae, and bacteria accumulating on the sensor, which obstructs its function and causes erroneous readings [20]. Moreover, particles and organic matter in the water can settle on the contact sensors, leading to inaccurate measurements [21].

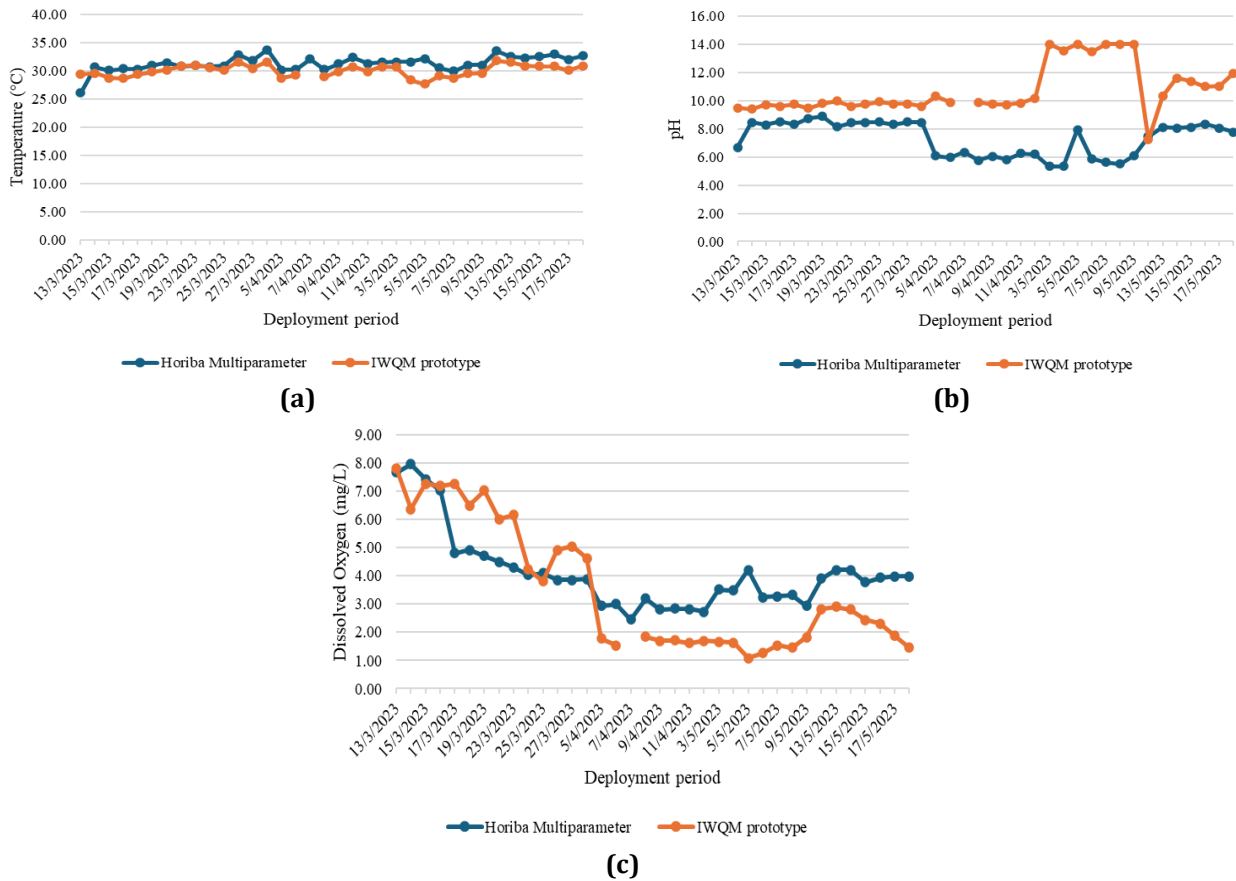


Fig. 4 The comparison between the Horiba Multiparameter and IWQM prototype data for (a) T parameter; (b) pH parameter; and (c) DO parameter during deployment tests at points 1 and 2

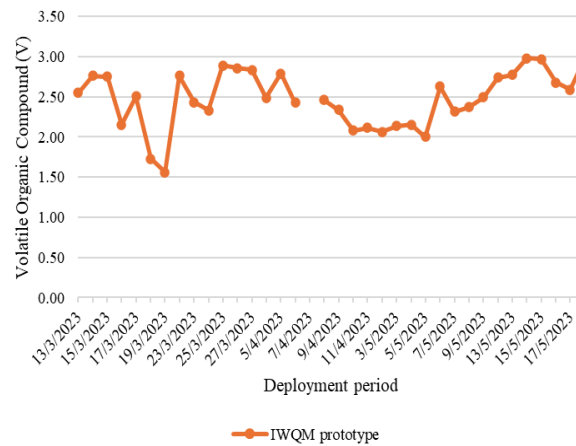


Fig. 5 The IWQM prototype VOC gas sensor measurement during the field deployment test

Fig. 5 illustrates the measurement of the VOC sensor of the IWQM prototype, indicating no VOC gas detection, as the voltage measurements were lower than 3.03V (the voltage limit set for petrol detection). In another study on breath analysers for blood glucose measurement, the sensor exhibited low conductivity in clean air and higher conductivity in the presence of acetone [22]. The voltage of the gas sensors used by Lu et al. [23] ranged between 0 and 5V; a higher voltage value indicated greater sensitivity of the sensor towards the substance.

3.2 Online Software Development

Fig. 6 shows the development of the IWQM prototype web application, which was based on Blynk Console. The water quality data was monitored remotely via Blynk website. On the other hand, there is the IWQM prototype mobile application, which utilizes the Blynk app. The Main View tab of the IWQM prototype app displayed

readings from each sensor. The user guide, which includes instructions and guidelines for using the IWQM prototype, is also shown in Fig. 7(a). While the Graphical View tab (Fig. 7(b)) contained two graphs, one displayed pH, TUR, and T data, while the other displayed EC, DO, and TDS of the collected data from the IWQM prototype during deployment.

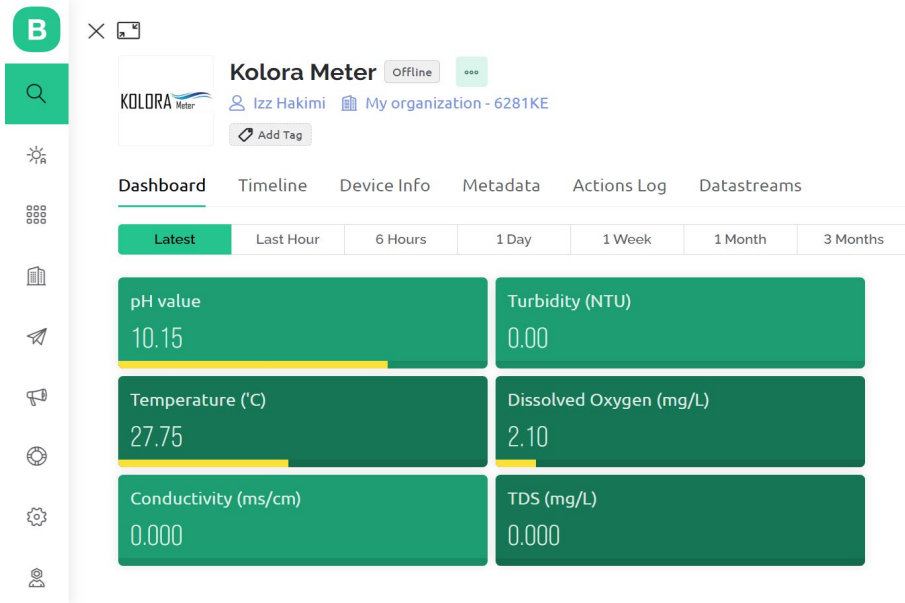


Fig. 6 The IWQM prototype web application based on Blynk Console

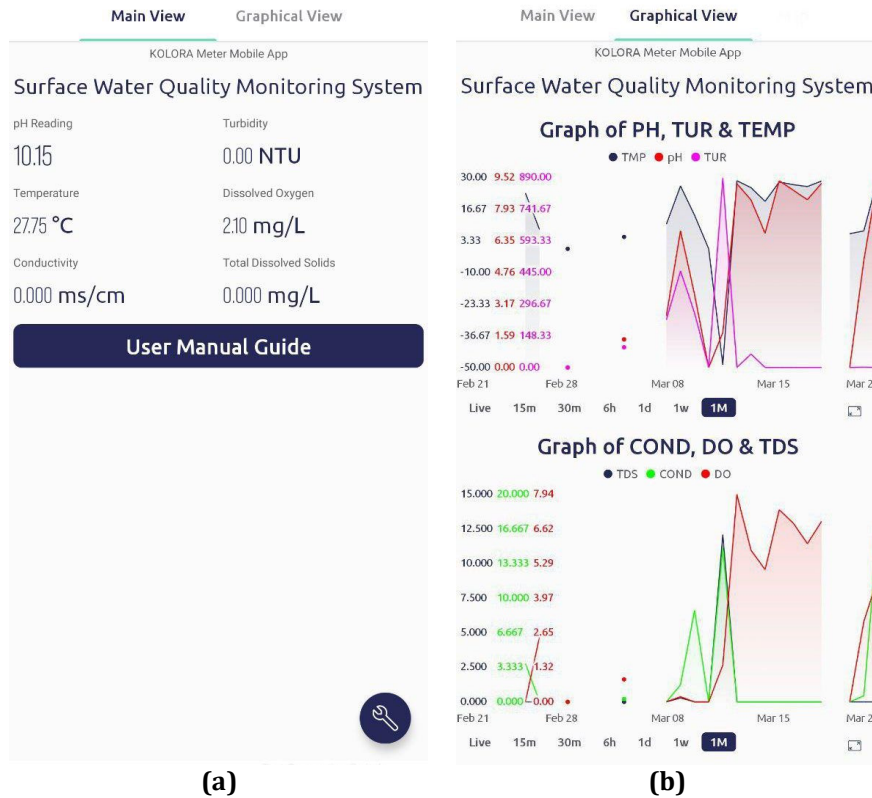


Fig. 7 IWQM prototype mobile application - (a) Main view; and (b) Graphical view of the collected data

3.3 Prototype Issues and Mitigation Strategies

Several issues with the IWQM prototype were identified during the field deployment test. The problem identified stems from a combination of hardware, software, and the nature of the surrounding environment itself. In terms of accuracy, the sensors produced accurate results in a laboratory setting.

3.3.1 Hardware Issues

The IWQM prototype experienced several hardware issues, including incorrect cable connection, sensor malfunction, degraded battery, relay switch failure to trip, and an internet connection problem. The IWQM prototype was deployed at Point 1 in the morning of May 12, 2023, but was found switched off in the evening. The issue was caused by an incorrect cable connection between the solar panel and the charging module, as illustrated in Fig. 8, which prevented the prototype from charging properly. The sensor problems included loose connections, water intrusion, and no recorded values from EC, TUR and TDS sensors. The pH sensor showed high readings in Week 4 due to a loose connection, which was fixed in Week 5. The TUR sensor failed because water entered the probe, as shown in Fig. 9. However, it was later sealed with a silicon sealant, as the probe material was made of low-surface-energy HDPE plastic, which is difficult to bond with glues and sealants. The same experience was reported by previous researchers [10], [24]. This issue was resolved by applying a structural adhesive to attach the HDPE probe to acrylonitrile-butadiene-styrene (ABS) 3D-printed material, thereby completely sealed the sensor from water ingress [24].

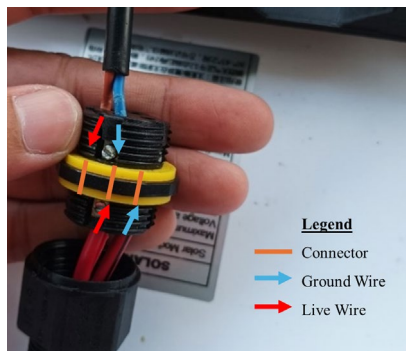


Fig. 8 The wrong wire connection from the solar panel to the charging module



Fig. 9 The water enters the TUR prototype sensor



Fig. 10 The shadow of the structure caused insufficient sunlight for solar charging in the evening at Point 1. The red circle shows the location of the IWQM prototype during the deployment period.

The EC, TUR, and TDS sensors did not provide any measurement data during the deployment test because of low sensor sensitivity and water intrusion issues. DO and pH sensors exhibit a slight deviation from the actual values, likely due to prolonged exposure during deployment. Since the sensors were deployed in natural water bodies over a long period, the accuracy of the sensors is significantly affected by interruptions due to human

activities, changes in temperature, salinity, and water flow resulting from weather fluctuations, which impact the readings of the potentiometric sensors [25]-[27]. This issue may be resolved by using an appropriate sensor housing and applying high-performance electronic components [28]. Chen & Han [29] also noted that although the sensors were calibrated before use, they can still face malfunction issues, resulting in erroneous readings.

The IWQM prototype was operated with a sealed lead-acid battery, the system can be operated for up to 18 hours at Point 2 during Week 3, but only 10 hours at Point 1 due to the shadow in the evening as shown in Fig. 10. By Week 4, battery capacity declined further, lasting only 3.5 hours, and worsened in Week 5, operating only in direct sunlight. The inadequate voltage input to the sensor could lead to errors during measurement [30]. Furthermore, unstable output voltage converter caused by the low battery can lead to higher voltage fluctuations, potentially damaging sensitive parts [31]. The battery should be able to retain more than 85% of its residual capacity for five days without receiving solar power at its maximum current consumption level [32].

3.3.2 Software Issues

The IWQM prototype has to undergo its self-checking initialisation before it can measure water quality data. The IWQM prototype would self-restart if it could not pass the self-initialisation protocol. Errors occurred when the prototype encountered a low battery condition, causing it to loop at the initialisation screen despite passing the self-check. The user would need to do troubleshooting on the IWQM prototype to ensure it can operate again. For smooth device operation, Manzoni et al. [33] developed a self-initialisation process that checks critical components and settings when the device is turned on. The IWQM prototype was observed to be able to connect to a Wi-Fi hotspot throughout the day, but it failed to reconnect the next day when the battery ran out overnight. A manual restart via the switch box was required for reconnection. The IWQM prototype could reconnect to Wi-Fi when it had sufficient power. To mitigate these issues, ensuring sufficient battery capacity is crucial, and implementing a periodic auto-restart could help maintain smooth operation. Efforts to save power by turning off unused features, such as the LED light and Wi-Fi antenna, are also recommended [33].

3.3.3 Nature of Surrounding Environment

The difficulties that must be overcome to ensure the prototype can function properly include severe weather and terrestrial animals at the monitoring site. The most common weather conditions at both places were described as clear, followed by partly cloudy and cloudy circumstances. Due to the presence of severe thunderstorms during rain and heavy rainfall, it is not feasible to conduct in-situ monitoring due to safety concerns. As the IWQM prototype was deployed on the water surface, its sensors and hull were covered with a layer of biofouling. Biofouling refers to the unintended growth of algae on the surface of sensors immersed in water [34]. Biofouling can affect the accuracy and longevity of sensors [24], [28], [35]. The data inaccuracy could be due to the fact that some sensors require periodically maintenance, as outlined in the manufacturer's guidelines, or the replacement of consumable parts [36]. On the other hand, aquatic animals such as snails and insects were observed climbing on the IWQM prototype hull during the monitoring. Fig. 11 shows apple snail (*Pomacea canaliculata*) eggs laid beneath the solar panel. A frogspawn was also found attached to the anchoring rope of the IWQM prototype, even though it was left for a few days. Hence, the cleaning of the IWQM prototype every two days would be necessary to ensure the system is able to measure the water quality correctly, as shown in Fig. 12. Every sensor would need to be cleaned of biofouling, as there would be significant deviation in the readings of the sensors except for the prototype T sensor, as the thermistor is the least affected [29]. In real-world applications, servicing work should be carried out at least once a month to ensure the monitoring system remains functional and operational [21].



Fig. 11 The presence of *Pomacea Canaliculata* eggs beneath the solar panel of the IWQM prototype.

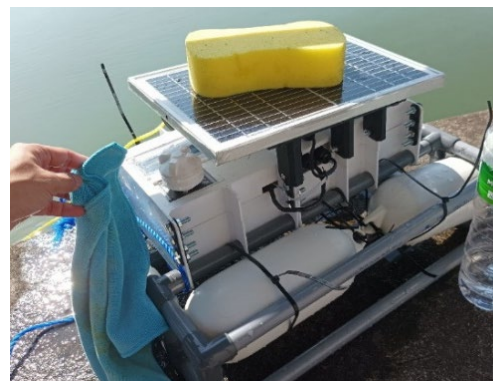


Fig. 12 The periodic cleaning of the IWQM prototype's body and sensors

4. Conclusions

Based on this study, a functional IWQM prototype using IoT technology has successfully designed and developed. The IWQM prototype included a self-initialisation checking algorithm to provide the user with information on whether the system was well-operated or malfunctioned and utilised the Blynk IoT Application (Blynk Apps and Web Dashboard). The IWQM prototype was well deployed in Points 1 and 2 from March to May 2023. The IWQM prototype experienced sensor reading issues, hardware errors, and adverse weather conditions, but successfully completed data collection. Issues were addressed and discussed for future improvements. Low-cost sensors exhibited significant deviations, particularly when operating in dynamic environments. The range of percentage errors for sensors at Point 1 were T (~0 to ~7%), pH (~8 to 53%), and DO (~1 to ~52%); and at Point 2, T (~2 to ~5%), pH (~58 to ~72%), and DO (~38 to ~62%). No readings were detected by EC, TDS, and TUR sensors due to technical issues, and no VOC pollution was found at both monitoring points. Therefore, regular maintenance and cleaning are recommended for the smooth operation of the IWQM prototype.

Acknowledgement

This research was funded by a grant from the UiTM Research Management Centre (RMC) (Covid-19 Sustainable Research Grant 600-RMC/LESTARICOVID/5/3 (007/2020). We would like to thank the School of Civil Engineering, College of Engineering, for providing the laboratory facilities and Putrajaya Corporation (PPJ) for allowing us to conduct field study at Putrajaya Lake and Wetland.

Conflict of Interest

The authors declare that they have no conflict of interest regarding the publication of this paper.

Author Contribution

*The authors confirm their contribution to the paper as follows: **Study conception and design:** Muhammad Izz Hakimi Zaidi Farouk, Zadariana Jamil, Mohd Fuad Abdul Latip; **Data collection:** Muhammad Izz Hakimi Zaidi Farouk, Normaliza Noordin, Yahzam Muhammad, Nik Norazlina Che Ya; **Analysis and interpretation of results:** Muhammad Izz Hakimi Zaidi Farouk, Zadariana Jamil; **Draft manuscript preparation:** Muhammad Izz Hakimi Zaidi Farouk, Zadariana Jamil, Mohd Fuad Abdul Latip, Nur Kamaliah Mustaffa, Azianabiha A. Halip. All authors reviewed the results and approved the final version of the manuscript.*

References

- [1] Kessler, F. (2021, January 6). Majority of Water Disruptions in 2020 Caused by Illegal Waste and Industrial Pollution. The New Straits Times. <https://www.nst.com.my/news/nation/2021/01/655050/majority-water-disruptions-2020-caused-illegal-waste-and-industrial>
- [2] Al-Mamun, A., & Zainuddin, Z. (2013) Sustainable river water quality management in Malaysia. IIUM Engineering Journal. <https://doi.org/10.31436/iiumej.v14i1.266>
- [3] Moe, C. L., & Rheingans, R. D. (2006). Global challenges in water, sanitation and health. Journal of Water and Health. <https://doi.org/10.2166/wh.2006.0043>
- [4] Jiao, D., & Luo, X. (2018). Water quality monitoring system based on LoRa. DEStech Transactions on Computer Science and Engineering. <https://doi.org/10.12783/dtcse/iece2018/26605>
- [5] Poch, M., Garrido-Baserba, M., Corominas, L., Perelló-Moragues, A., Monclús, H., Cermerón-Romero, M., Melitas, M., Jiang, S.C. & Rosso, D. (2020) When the fourth water and digital revolution encountered COVID-19. Science of the Total Environment. <https://doi.org/10.1016/j.scitotenv.2020.140980>
- [6] Geetha, S., & Gouthami, S. J. S. W. (2016). Internet of things enabled real time water quality monitoring system. Smart Water. <https://doi.org/10.1186/s40713-017-0005-y>
- [7] Park, J., Kim, K. T., & Lee, W. H. (2020). Recent advances in information and communications technology (ICT) and sensor technology for monitoring water quality. Water. <https://doi.org/10.3390/w12020510>
- [8] Paepae, T., Bokoro, P. N., & Kyamakya, K. (2021). From fully physical to virtual sensing for water quality assessment: A comprehensive review of the relevant state-of-the-art. Sensors. <https://doi.org/10.3390/s21216971>
- [9] Kumar, D. S., Askarunisa, A., & Kumar, R. M. (2020). Embedded processor based automated assessment of quality of the water in an IoT background. Microprocessors and Microsystems. <https://doi.org/10.1016/j.micpro.2020.103167>

- [10] Eskin, M. G., Torabfam, M., Psillakis, E., Cincinelli, A., Kurt, H., & Yüce, M. (2019). Real-time water quality monitoring of an artificial lake using a portable, affordable, simple, arduino-based open source sensor. *Environmental Engineering-Inženjerstvo okoliša*. <https://doi.org/10.37023/ee.6.1.2>
- [11] Paramarta K. M., & Amuta, I. (2020). Online water waste monitoring system for textile industry. *IEEE ITB 2019 Innovation Contest*. https://www.researchgate.net/publication/341568429_IEEEITBSB2019_InnovationContest_Preliminary_HMTE_Unpad
- [12] Islam, M. M., Arefin, M. S., Khatun, S., Mokarrama, M. J., & Mahi, A. M. (2021). Developing an IoT Based Water Pollution Monitoring System. In Chen, J. I. Z., Tavares, J. M. R. S., Shakya, S., & Ilyasu, A. M. (eds) *Image Processing and Capsule Networks. ICIPCN 2020. Advances in Intelligent Systems and Computing*. https://doi.org/10.1007/978-3-030-51859-2_51
- [13] Zulkifli, S. N., Rahim, H. A., & Lau, W. J. (2018). Detection of contaminants in water supply: A review on state-of-the-art monitoring technologies and their applications. *Sensors and Actuators B: Chemical*. <https://doi.org/10.1016/j.snb.2017.09.078>
- [14] Bharani Baanu, B., & Jinesh Babu, K. S. (2022). Smart water grid: A review and a suggestion for water quality monitoring. *Water Supply*. <https://doi.org/10.2166/ws.2021.342>
- [15] AlMetwally, S. A. H., Hassan, M. K., & Mourad, M. H. (2020). Real time internet of things (IoT) based water quality management system. *Procedia CIRP*. <https://doi.org/10.1016/j.procir.2020.03.107>
- [16] Pule, M., Yahya, A., & Chuma, J. (2017). Wireless sensor networks: A survey on monitoring water quality. *Journal of Applied Research and Technology*. <https://doi.org/10.1016/j.jart.2017.07.004>
- [17] Lin, J. Y., Tsai, H. L., & Lyu, W. H. (2021). An integrated wireless multi-sensor system for monitoring the water quality of aquaculture. *Sensors*. <https://doi.org/10.3390/s21248179>
- [18] Hakimi, I. M., & Jamil, Z. (2021). Development of water quality monitoring device using Arduino UNO. *IOP Conference Series: Materials Science and Engineering*. <https://doi.org/10.1088/1757-899x/1144/1/012064>
- [19] Thakur, A., & Devi, P. (2024). A comprehensive review on water quality monitoring devices: materials advances, current status, and future perspective. *Critical Reviews in Analytical Chemistry*. <https://doi.org/10.1080/10408347.2022.2070838>
- [20] Delauney, L., Compere, C., & Lehaitre, M. (2010). Biofouling protection for marine environmental sensors. *Ocean Science*. <https://doi.org/10.5194/os-6-503-2010>
- [21] Wong, Y. J., Nakayama, R., Shimizu, Y., Kamiya, A., Shen, S., Rashid, I. Z. M., & Sulaiman, N. M. N. (2021). Toward industrial revolution 4.0: Development, validation, and application of 3D-printed IoT-based water quality monitoring system. *Journal of Cleaner Production*. <https://doi.org/10.1016/j.jclepro.2021.129230>
- [22] Hassan, T., Rehman, T., Aziz, Q. A., & Salman, A. (2018). Blood glucose level measurement from breath analysis. *International Journal of Medical, Medicine and Health Sciences*. <https://doi.org/10.5281/zenodo.1474537>
- [23] Lu, X., Wang, J., Lu, G., Lin, B., Chang, M., & He, W. (2019). Quality level identification of West Lake Longjing green tea using electronic nose. *Sensors and Actuators B: Chemical*. <https://doi.org/10.1016/j.snb.2019.127056>
- [24] Trevathan, J., Read, W., & Schmidtke, S. (2020). Towards the development of an affordable and practical light attenuation turbidity sensor for remote near real-time aquatic monitoring. *Sensors*. <https://doi.org/10.3390/s20071993>
- [25] Huang, Y., Wang, T., Xu, Z., Hughes, E., Qian, F., Lee, M., ... & Li, B. (2019). Real-time in situ monitoring of nitrogen dynamics in wastewater treatment processes using wireless, solid-state, and ion-selective membrane sensors. *Environmental Science & Technology*. <https://doi.org/10.1021/acs.est.8b05928>
- [26] Lenkopane, M., Werner, A. D., Lockington, D. A., & Li, L. (2009). Influence of variable salinity conditions in a tidal creek on riparian groundwater flow and salinity dynamics. *Journal of Hydrology*. <https://doi.org/10.1016/j.jhydrol.2009.07.004>
- [27] Lehmann, R., & Totsche, K. U. (2020). Multi-directional flow dynamics shape groundwater quality in sloping bedrock strata. *Journal of Hydrology*. <https://doi.org/10.1016/j.jhydrol.2019.124291>
- [28] Wang, Z., Song, H., Watkins, D. W., Ong, K. G., Xue, P., Yang, Q., & Shi, X. (2015). Cyber-physical systems for water sustainability: Challenges and opportunities. *IEEE Communications Magazine*. <https://doi.org/10.1109/MCOM.2015.7105668>

- [29] Chen, Y., & Han, D. (2018). Water quality monitoring in smart city: A pilot project. *Automation in Construction*. <https://doi.org/10.1016/j.AUTCON.2018.02.008>
- [30] Lockridge, G., Dzwonkowski, B., Nelson, R., & Powers, S. (2016). Development of a low-cost arduino-based sonde for coastal applications. *Sensors*. <https://doi.org/10.3390/s16040528>
- [31] Trevathan, J., Schmidtke, S., Read, W., Sharp, T., & Sattar, A. (2021). An IoT general-purpose sensor board for enabling remote aquatic environmental monitoring. *Internet of Things*. <https://doi.org/10.1016/J.IOT.2021.100429>
- [32] Martínez, R., Vela, N., El Aatik, A., Murray, E., Roche, P., & Navarro, J. M. (2020). On the use of an IoT integrated system for water quality monitoring and management in wastewater treatment plants. *Water*. <https://doi.org/10.3390/W12041096>
- [33] Manzoni, P., Merzougui, S. E., Palazzi, C. E., & Pozzan, P. (2023). A resilient LoRa-based solution to support pervasive sensing. *Electronics*. <https://doi.org/10.3390/electronics12132952>
- [34] Jan, F., Min-Allah, N., & Düstegör, D. (2021). Iot based smart water quality monitoring: Recent techniques, trends and challenges for domestic applications. *Water*. <https://doi.org/10.3390/w13131729>
- [35] Adu-Manu, K. S., Tapparello, C., Heinzelman, W., Katsriku, F. A., & Abdulai, J. D. (2017). Water quality monitoring using wireless sensor networks: Current trends and future research directions. *ACM Transactions on Sensor Networks (TOSN)*. <https://doi.org/10.1145/3005719>
- [36] Rastegari, H., Nadi, F., Lam, S. S., Ikhwanuddin, M., Kasan, N. A., Rahmat, R. F., & Mahari, W. A. W. (2023). Internet of things in aquaculture: A review of the challenges and potential solutions based on current and future trends. *Smart Agricultural Technology*. <https://doi.org/10.1016/j.atech.2023.100187>