Smart Water Quality Monitoring with the Implementation of IoT

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Abstract. Globally, an estimated 80% of industrial and municipal wastewater is discharged into the environment without proper treatment, adversely affecting water quality. To ensure the sustainability and reliability of water quality, real-time monitoring systems are essential for maintaining optimal water quality and mitigating environmental risks. While traditional water quality monitoring methods have served as a foundation for understanding aquatic ecosystems, smart monitoring systems integrating Internet of Things (IoT) technology have become a game changer in water management. Unlike traditional methods, which rely on manual data collection, smart water monitoring systems provide continuous, real-time insights into crucial water quality. This project aims to develop and design an embedded system architecture to perform real-time water quality monitoring with the integration of IoT technology and display the water quality in a graphical format via an Android app (Blynk). The entire embedded system was based on the Arduino platform and the Blynk cloud server. ESP32 module was used to log temperature, PH, turbidity, and TDS sensor data. By utilising the compatibility of IoT, these systems enable remote monitoring, immediate alerts for deviations, and data-driven decision-making. Initial tests were gathered from Taman Tasik Seksyen 7 on 19th May. Several parameters were observed in the initial test, namely water temperature (30.37 °C), pH (9.97), turbidity (33.00 ppm), and TDS (180.00 ppm). The water quality readings indicate that the water can be used for water supply with conventional treatment or for recreational activities involving bodily contact. This demonstrates the possibility of continuously monitoring water quality on-site and alerting users to any alarming lake conditions if they exist. This proactive approach enhances the efficiency and productivity of water quality inspections and minimises environmental risks.

Keywords: Water Quality; IoT; Temperature; pH: turbidity; TDS.

1 Introduction

Water quality issues threaten environmental sustainability, public health, and socio-economic development. The country's rivers face a dual threat from point and non-point sources of pollution, including sewage treatment plants, agro-industry, manufacturing, and polluted runoff from agricultural areas. This has led to a significant decline

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in river water quality, making it increasingly challenging to treat for use [1]. While most drinking water standards in Malaysia are met, some studies have found high levels of contaminants like copper, cadmium, iron, and lead in tap water, attributed to galvanised plumbing and pipe materials corrosion. Microbiological contamination in tap water is associated with growing biofilms inside pipelines [2].

Furthermore, fishponds, often located near agricultural and industrial areas, are at risk of pollution from fertilisers, pesticides, and other chemicals. This can cause changes in water pH, temperature, turbidity and total dissolved solids, making it difficult for fish to thrive, leading to disease and mortality [3]. These challenges, coupled with inadequate water circulation, poor water quality management, and lack of regular water testing, underscore the need for a proper water quality monitoring system to maintain good water quality in lakes or reservoirs.

Traditional methods of monitoring water quality have several limitations that can affect the efficiency, accuracy, and overall management of water resources. This method typically relies on manual sampling and laboratory testing, which are time-consuming and labour-intensive, resulting in delayed results and limited frequency of monitoring. Additionally, traditional monitoring requires expensive specialised equipment, expert personnel, and laboratory facilities. The costs associated with sample collection, transportation, and analysis are significant barriers, especially for re-source-constrained areas [4]. Furthermore, traditional methods rely on manual sample collection and laboratory analysis, which can take days to weeks to produce the results [5]. This delay prevents immediate action in response to the water quality issue. With immediate access to water quality data, authorities can make timely decisions to address contamination or implement corrective actions. The delayed response can lead to prolonged exposure to unsafe water [6].

Current research on water quality monitoring focuses on developing advanced technologies to improve the efficiency, accuracy, and real-time monitoring of water quality parameters. Modern IoT-based water quality monitoring systems address many of these issues, aligning with the principles of IR4.0 and emphasising the integration of advanced technologies into industrial processes. They provide continuous, real-time data on various water quality parameters, allowing for timely detection and response to any issues, preventing problems from becoming more severe and costly to address [7]. IoT devices can transmit data wirelessly, allowing for remote access and analysis of water quality information. This is particularly useful for monitoring water quality in remote or hard-to-reach locations [8]. IoT-based monitoring systems can automate the water quality assessment, allowing for more efficient and cost-effective monitoring. Automated systems can also trigger immediate alerts when parameters exceed predefined thresholds, enabling quick action to mitigate issues [4],[9].

Additionally, IoT sensors can collect data on the factors that impact equipment performance, such as pumps and filtration systems. The data can help predict when maintenance is needed, ensuring the equipment always operates at peak performance and reducing the likelihood of failures [7]. Wireless Sensor Networks (WSN) are used to monitor water quality parameters in remote areas. These networks use low-power sensors and wireless communication protocols to transmit data to central locations for analysis and monitoring [10]. Moreover, many research projects focus on developing userfriendly mobile applications that allow users to monitor water quality in real-time, receive alerts, access historical data conveniently, and integrate with Google Maps for rapid judgement and analysis [11].

The implementation of IoT in water quality monitoring offers a range of benefits, including continuously monitoring access to water quality parameters, enabling early detection of deviations from ideal water quality that allows for prompt corrective actions. With real-time data and automated monitoring, the authorities can make informed decisions quickly, ensuring optimal water conditions. The economic benefits of IoT-based water quality monitoring systems provide reassurance about the return on investment, making them a sound choice for water resource management.

Thus, with the implementation of IoT in water quality monitoring, this project may significantly transform the conventional methods of monitoring water. This project uses several sensors to monitor temperature, pH, turbidity, and total dissolved solids (TDS), using a low-power microcontroller with integrated Wi-Fi and Bluetooth capabilities and an ESP32 module for data transmission. An Android application called Blynk was used for data display because it provides a simple and intuitive interface for creating custom dashboards on smartphones or web browsers to visualise water quality data, making it easier to identify trends and patterns [12]. Besides, Blynk includes an alert system configured to send notifications when water quality parameters exceed predefined thresholds. This ensures that users are quickly informed of any changes in water quality, enabling quick response [12]. Furthermore, Blynk integrates seamlessly with IoT devices, allowing the use of sensors and other devices to monitor water quality parameters [12].

2 Methodology

2.1 System Design and Architecture

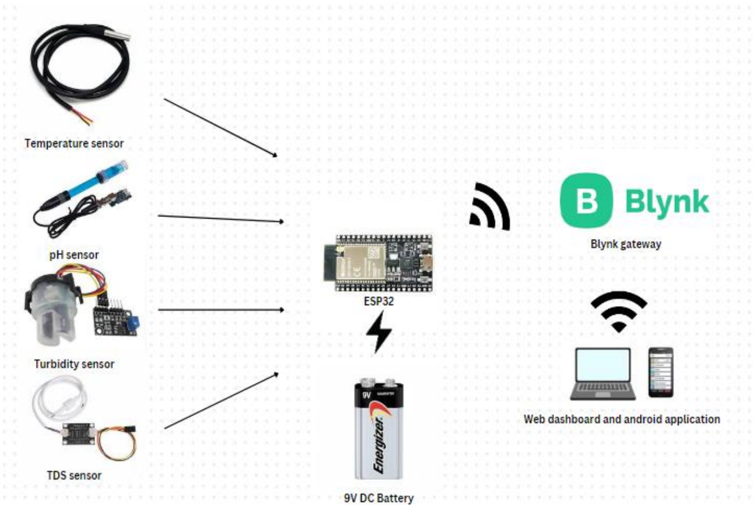

Fig. 1. System architecture

Fig. 1 shows the overall system architecture for the water monitoring system. The water quality index (WQI), based on the National Water Quality Standards for Malaysia (NWQS), uses six parameters to determine water quality: ammoniacal nitrogen, biochemical oxygen demand (BOD), chemical oxygen demand (COD), dissolved oxygen (DO), pH, and total suspended solids (TSS) [13]. The system was designed to use appropriate sensors to monitor pH, TDS, temperature, and turbidity. In this initial design, the turbidity sensor is a proxy for TSS and a crucial component of our system's efficiency. Although the turbidity reading does not measure the weight or volume of suspended particles like TSS, several previous studies have shown that turbidity can be used as a surrogate for TSS while providing a quick water quality assessment [14,15]. This feature enhances the efficiency of our system, providing a fast and reliable water quality assessment of two out of six parameters for the WQI.

The ESP32 microcontroller converts the sensor's value from analogue to digital. Data transmission to the Blynk server via an ESP32 was achieved by establishing a Wi-Fi connection, initialising the Blynk library with the authentication token and Wi-Fi credentials, and using the Blynk.virtualWrite() function to send sensor data to the server. This allows users to remotely monitor and visualise sensor readings using the Blynk app or dashboard.

To ensure a stable Wi-Fi connection, during the field test, a Bluetooth Wi-Fi connection was used with the mobile device placed inside the PVC box, along with all the other electronic components (see Fig. 2).

2.2 Sensor Integration and Calibration

Fig. 1 depicts the system architecture for the water quality monitoring system. The system is powered by a 9V DC battery, which supplies power to the ESP32 microcontroller and sensors. This system is configured to collect data at specific intervals, such as once every hour for the field test, rather than continuously capturing data. A 4.7kΩ resistor is used as a pull-up resistor to counter the high impedance of the temperature sensor and reduce the impact of noise generated by interconnecting wires, which could otherwise result in inaccurate sensor output. Table 1 provides the connection output for each component.

Table 1. Connection output

Sensor	Pinout
Temperature sensor	GPIO32
Ph sensor	GPIO33
Turbidity sensor	GPIO34
Total Dissolve Solid sensor	GPIO35

2.3 Sensor Calibration

Calibration of Arduino sensors is necessary to ensure the accuracy and reliability of the data they produce. Over time, sensors can deviate due to factors such as ageing and environmental conditions. Calibration involves adjusting the sensor readings to match laboratory-grade sensors. This process ensures that the data collected by the sensors are accurate and can be trusted for decision-making purposes [16]. Water samples are taken from Taman Tasik Seksyen 7, Shah Alam. The sensors were then tested with laboratory-grade sensors from Environmental Lab 2. The test was conducted five times, each for 1 minute, and the data were tabulated as shown below. The same samples were then tested with Arduino sensors, and the results were recorded. The results were compared, and the differences were recorded. The sensors were calibrated by modifying the code to adjust their readings accordingly. After calibration, the sensors were re-tested and calibrated until the readings were within the acceptable tolerance.

pH sensor calibration. The pH sensor is calibrated by dipping it in the standard buffer solution provided, measuring the values, and comparing them. An offset value can be added to the sensor code to calibrate it. The calibration was verified by comparing the value in the Serial Monitor with the result from the laboratory pH sensor. Table 2 shows the results before and after the calibration process.

Table 2. Results from calibration of pH sensor

Test	Laboratory Buffer pH4		Arduino Buffer pH4		Arduino Buffer pH7		Arduino Buffer pH7	
	Before	After	Before	After	Before	After	Before	After
1	4.19	4.19	5.59	4.24	7.01	7.01	8.29	7.21
2	4.23	4.23	5.73	4.21	7.01	7.03	8.52	7.28
3	4.11	4.11	5.98	4.12	7.04	7.02	9.01	7.19
4	4.05	4.05	5.96	4.07	7.02	7.05	8.89	7.04
5	4.01	4.01	6.01	4.06	7.01	7.01	8.75	7.11

Turbidity sensor calibration. The Turbidity sensor electrode was dipped in a Taman Tasik Seksyen 7 water sample. The calibration can be done by adding a calibration value in the sensor code. We verified the calibration by comparing the value in the Serial Monitor with the result from the laboratory turbidity sensor. Table 3 shows the results before and after the calibration process.

Table 3. Results from calibration of turbidity sensor

Test	Laboratory (NTU)		Arduino (NTU)	
	Before	After	Before	After
1	17.2	17.0	49.2	17.3
2	17.5	16.7	48.4	17.3
3	17.6	16.6	45.6	16.9
4	17.3	16.5	41.8	17.0
5	17.3	16.4	39.2	17.1

TDS sensor calibration. The TDS sensor electrode was dipped in the same water sample used for the calibration. The calibration can be done by adding a calibration value to the sensor code. We verified the calibration by comparing the value in the

Serial Monitor with the result from the laboratory TDS sensor. Table 4 shows the results before and after the calibration process.

Table 4. Results from the calibration of the TDS sensor

Test	Laboratory (ppm)		Arduino (ppm)	
	Before	After	Before	After
1	220.3	221.5	443.2	221.9
2	222.1	222.3	445.3	221.7
3	221.2	221.9	446.7	221.8
4	221.0	221.7	445.9	221.8
5	220.5	222.8	448.1	221.9

2.4 Prototype development

A 10 cm x 8 cm x 4 cm PVC box houses all the buoy electronic components (Fig. 2). This IP56-rated waterproof box protects the electronics from water damage caused by rainfall and splashes. Inside the box are all the sensor modules, the ESP32 module, an expansion board, and a battery. Meanwhile, the sensor probes were placed inside a PVC tube. A tube cap drilled with several holes was placed at the end of the PVC tube, submerging the probes in the water. Using a mild steel plate through a waterjet process, a base is custom fabricated to place the PVC on the buoy (Fig. 3).

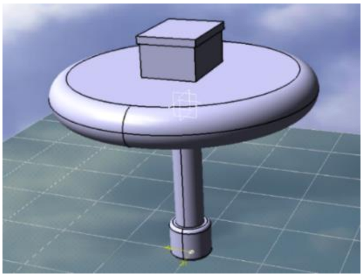

Fig. 2. Illustration of complete prototype

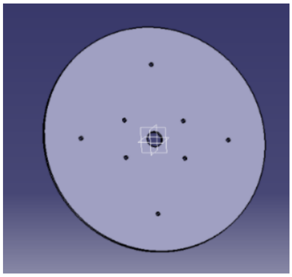

Fig. 3. Base plate for electronic components

2.5 Field testing

Field testing ensures the water quality monitoring system functioned correctly and reliably in a water reservoir environment. It helps identify and rectify potential issues, verify sensor accuracy, and validate system performance under actual conditions. This thorough testing process helps avoid costly failure and ensures the system provides reliable data to support aquaculture management and decision-making. Fig. 4 shows the field test with the prototype successfully conducted at Taman Tasik Seksyen 7, Shah Alam. The test began at 11 a.m. and concluded at 3 p.m. with hourly water quality data collection.

Fig. 4. Field test at Taman Tasik Seksyen 7

3 Results and Discussions

Fig. 5 shows the web dashboard for the water quality monitoring system, with a meter-like (Fig. 5(a)) dashboard for real-time data and graph-like (Fig. 5 (b) and (c)) data for hourly data. Both were available for the user.

(a) (b) (c)

Fig.5. Web dashboard for temperature, pH, turbidity and TSD readings. (a) Dashboard (b) Temperature and pH readings (c) Turbidity and TDS readings

During the field test, there was heavy rain from 12 p.m. until 4 p.m. The rain significantly affected the water quality parameters. The impact of rain on water quality is multifaceted, influencing parameters like turbidity, temperature, TDS, and pH. Rain often causes runoff, which carries soil, increasing turbidity. The disturbance of sediments from the waterbed due to increased flow also elevates turbidity levels. Increased turbidity reduces light penetration, which affects species that rely on visual cues for feeding, mating, and predator avoidance, making it more difficult for them to survive in turbid water [17]. At the same time, TDS levels increased due to runoff carrying dissolved minerals, salts, and pollutants. Increasing TDS disrupts osmoregulation—the process by which organisms maintain fluid balance and the concentration of salts. This can lead to physiological stress, reduced growth, and reproductive issues [18]. This can also be observed during the field test, as shown in Fig. 6 and 7 on turbidity and TDS readings, respectively. Based on the gathered data, the turbidity value falls well within the acceptable range for Class IIA and IIB, making it suitable for recreational activities involving bodily contact and also for water supply, with conventional treatment required [13]. TDS data falls under Class I, suitable for water supply with practically no treatment necessary [13].

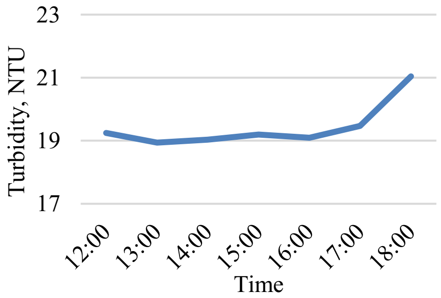

Fig. 6. Graph of turbidity against time

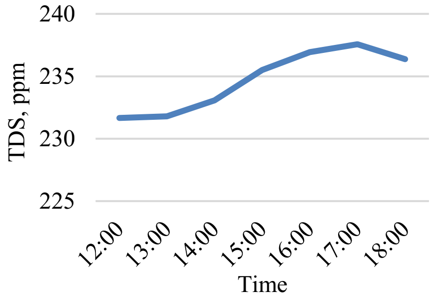

Fig. 7. Graph of TDS against time

Fig. 8 shows that the temperature decreases as the rainwater offers a cooling effect to the ambient temperature of water bodies, especially during warm seasons. Temperature is critical in aquaculture, influencing metabolic rates, oxygen levels, and reproduction. For some species, slight temperature changes can lead to mortality [17]. Fig.9 shows that the pH readings of the water became somewhat acidic, as rainwater typically has a slightly acidic pH due to dissolved carbon dioxide forming carbonic acid. Acid rain, caused by sulphur dioxide and nitrogen oxides from industrial pollution, can further lower the pH of natural water, making it more acidic. This change in pH can affect aquatic life and chemical processes in the water [19]. However, the lake's pH level falls within the acceptable range of 6.5 to 8.5 for Class 1 water [13].

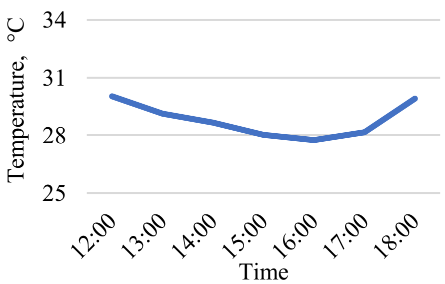

Fig. 8. Graph of temperature against time

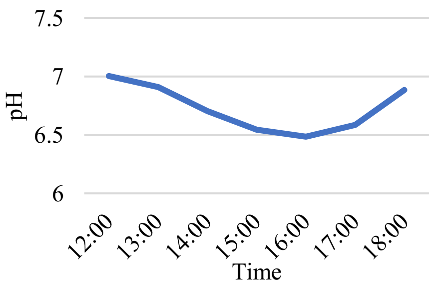

Fig. 9. Graph of pH against time

3.1 Issues and Challenges

Several issues were faced during the field test. First, the readings from the sensors deviate even after calibration. This is because temperature changes affect sensor readings. Most sensors have a specific operating temperature range, and deviations from this range can lead to inaccuracies. Moreover, an imbalance in voltage stability might affect the readings. During calibration, the voltage supply is from the laptop, whereas during the field testing, the power source is from a 9V DC battery. Therefore, a change in power source is seen as crucial for the project. To avoid this, a high-capacity rechargeable lithium-ion battery can provide a longer runtime between charges [20]. The battery pack combined with a solar panel can provide a renewable energy source, reducing the need for frequent battery replacements. At the same time, there are long-term cost savings due to the reduced need for replacement batteries.

Secondly, the sensors might be clogged with dirt as they are not designed to be submerged in water for an extended period. To cope with this issue, the sensors must not be exposed to fluctuating environmental conditions, such as sudden temperature changes or varying light conditions. It is better to use shielding and proper housing to minimise these effects.

Thirdly, the absence of long-range (Lo-Ra) technology has reduced communication range. Typical Wi-Fi or Bluetooth have a much shorter range, often limited to tens or hundreds of meters. This led to communication problems where data was not reliably transmitted to the central server [21]. As an alternative, a receiver was placed inside the PVC box along with the ESP32 modules for a successful data transmission.

4 Conclusion

An IoT water quality monitoring system was successfully developed and tested. The embedded system performs real-time water quality monitoring by integrating IoT and utilising an Android application to display water parameters in a graphical format. Four water parameters were monitored: temperature, pH, turbidity, and TDS. Additionally, the battery-powered system enables 24-hour water quality monitoring without human intervention. ESP32 is the mainboard used in this project to log and transmit data to the cloud. The cloud function used in this project is Blynk Cloud, as it can store data, process data, and send notifications to mobile devices. A field test was conducted at Taman Tasik Seksyen 7 on 19th May. Several parameters were observed in the field test, namely water temperature (averaged 30.37 °C), pH (averaged 9.97), turbidity (averaged 33.00 ppm), and TDS (averaged 180.00 ppm). Based on the data collected, Taman Tasik Seksyen 7's water quality falls within Class I to IIB. This means that it is suitable for use as a water supply with little to conventional treatment or for recreational activities involving body contact. This shows that continuous monitoring can be done on-site to measure the water quality and alert users of alarming lake conditions (if present). The concept can be further extended to other water reservoir facilities to provide water quality reports in a ton time proactive approach enhances the efficiency and productivity of water quality inspections and minimises environmental risks.

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