Jurnal Ilmu Fisika
Vol. 16, No. 1, March 2024, pp. 1–12
ISSN: 1979-4657 (Print); 2614-7386 (Online)
https://doi.org/10.25077/jif.16.1.1-12.2024

Jurnal Ilmu Fisika
Open Access

Development of River Flow and Water Quality Using IOT-based Smart Buoys Environment Monitoring System

Subhan Fahmi Nasution[1],Harmadi Harmadi[1], Suryadi Suryadi[2], Bambang Widiyatmoko[2]
[1] Department of Physics, Universitas Andalas, Padang, 25163, Indonesia.
[2] Research Center for Photonics, National Research and Innovation Agency (BRIN), BJ.Habibie Science and Tecnology Park, Banten, 15314, Indonesia

Article Info

Article History:

Received September 08, 2023
Revised September 19, 2023
Accepted September 19, 2023
Published online September 22, 2023

Keywords:

Internet of Things
River flow
Water quality
ESP32
GPS

Corresponding Author:

Harmadi Harmadi,
Email: harmadi@sci.unand.ac.id

ABSTRACT

Efficient and accurate river water quality monitoring is needed to support laboratory testing based on on-site sampling. Therefore, we have developed a monitoring system for river flow and water quality using sensor-equipped buoys and the Internet of Things (IoT) concept. An ESP32 NodeMCU microcontroller integrated with WiFi and compatible with Arduino IDE is used in the system. The buoy is equipped with GPS to determine the position and flow speed and sensors to measure water quality parameters of pH and temperature. Data on position, flow velocity, and water quality parameters are transmitted over a WiFi network using the MQTT protocol. The data is recorded by the buoy and uploaded and displayed on the adafruit.io platform. Positioning was done by comparing the values displayed on the Neo-6M GPS with the Maps application on the smartphone. The results show that the GPS coordinate values are accurate. The water quality parameter values obtained have an error rate of 3.3% for the pH sensor and 1.02% for the temperature sensor. Thus, the system we have developed has the potential to be used as a substitute for field sampling-based river water quality monitoring systems.

1. INTRODUCTION

Water pollution is one of the significant threats these days as drinking water is increasingly contaminated and polluted. Shortage of clean water supply is a problem in several countries, including Indonesia (Jan et al., 2021). Water pollution can be triggered by various means; one of the leading causes of pollution is industrial and municipal waste discharge (Kementerian Lingkungan Hidup dan Kehutanan Republik Indonesia, 2017). Through the Environmental Agency (BLH), the government has monitored industrial waste to maintain water quality. However, ensuring that industries report wastewater treatment plant result data is often challenging. In practice, the waste discharged into rivers still contains chemicals that damage the environment and can potentially harm human health and aquatic biota (Masykur et al., 2018). According to information from the World Health Organization (WHO), about 2 billion people worldwide are forced to drink water polluted by sewage, increasing the disease risk (Lakshmikantha et al., 2021).

Raw water quality, especially river water, is usually checked by taking samples at the test site through laboratory tests (Park et al., 2020). Manual sampling often affects the accuracy of measurement results, especially if the difference in measurement parameters is less than 5%. Efforts that are more practical, efficient, and fast in conducting raw water testing are needed to fully determine polluted water's flow and quality (Damayanti et al., 2022).

Based on the Government Regulation of the Republic of Indonesia No. 38 of 2011 concerning rivers, river water pollution must be avoided by various measures such as setting the maximum allowable pollution limit, identifying the source of wastewater entering the river, establishing wastewater discharge requirements, and prohibiting the discharge of wastewater into the river (Pemerintah Republik Indonesia, 2011). In addition, the flow rate of river water is also essential in monitoring river conditions. Wastes discharged into the river can affect the flow of water, reduce the flow speed, or even inhibit the flow altogether (Putro & Suryono, 2017).

According to the Regulation of the Minister of Health of the Republic of Indonesia No. 32 Year 2017, water used for daily needs must meet specific quality standards. These standards include a pH ranging from 5.0 to 9.0 and a water temperature from 15°C to 35°C (Menteri Kesehatan Republik Indonesia, 2017). Although the pH of water does not have a health-based guideline value set by the WHO in its Guidelines for Drinking Water Quality, it should be in the range of 6.5 to 8.5. Water temperature is critical in quality control and should be kept outside 25 to 50°C (Herschy, 2012). In this context, flow and water quality monitoring is essential for evaluating the quality of water sources and rivers used (Akbar et al., 2019).

Research related to river water quality monitoring system has been developed and some investigators has developed sophisticated monitoring systems using sensors to collect data related to water flow and water quality parameters. These systems have used various sensors to measure various parameters. Previous research has also involved using GPS-equipped buoys to collect path, route, and flow speed data (Soeboer et al., 2018). In addition, water quality parameters such as pH, temperature, and dissolved oxygen have been investigated by sending sensor data through a GSM transmission module, which is then displayed on an LCD screen connected to an Arduino (Gokulanathan, 2019). This monitoring system has sensors that measure parameters such as turbidity, pH, water level, environmental humidity, and water temperature. Data from these sensors is processed by a Microcontroller (MCU) and sent to the Cloud through the ThinkSpeak application based on the Internet of Things (IoT) for water quality monitoring (Pasika & Gandla, 2020). In addition, other research on pH, gas, and ultrasonic sensors for measuring water parameters in dams has used sensors connected to WiFi modules and transferred data to the Blynk application (Roshidi & Thirunavakkarasu, 2021). In addition, developing an IoT-based Intelligent Water Quality Monitoring System with cloud and deep Learning methods has been successfully carried out to monitor water quality in real-time. The system aims to improve the efficiency of water quality monitoring, replacing manual processes involving laboratory testing (Ajith Jerom & Manimegalai, 2020).

A water quality monitoring system has been developed in response to these challenges. This system enables real-time monitoring of water quality by utilizing IoT technology.Water quality parameters, such as pH and temperature, are measured by various sensors connected to the platform through a microcontroller system. MQTT technology is also used to enable simultaneous data flow between the sensors and the server, improving the responsiveness and accuracy of the system. The buoy is equipped with GPS and water quality sensors, such as pH and temperature sensors, to collect high-accuracy data on the path, route, flow speed, and position of objects. The data generated by these sensors is recorded and rapidly transmitted through the ESP32 device using the internet network.

This monitoring system is designed to operate online and in real-time, integrating the Smart Environment concept in water quality monitoring. Smart environment is a concept that uses Internet of Things (IoT) technology and devices to conduct more innovative and more efficient monitoring of its environment. This research aims to develop a system for monitoring the flow and quality of river water polluted by sewage by looking at factors such as pH and temperature. This research also has significant benefits in identifying polluted spots on the river surface. The results can be used to improve environmental rehabilitation and protection and preventive action in policy-making through Smart Environment technology. More efficient and real-time monitoring enables more informed decision-making and rapid response to changes in river water quality.

2. METHOD

2.1 Hardware Design of River Flow and Water Quality Monitoring System using smart environment-based buoys

The prototype device design used to develop the river flow and water quality monitoring system uses Smart Environment-based buoys, GPS systems, sensors, and ESP32 in the prototype design process. In this context, "Smart Environment" involves using sensors and connected IoT devices to collect real-time or near real-time river flow data and water quality. This data can then be analyzed and utilized to improve monitoring and management of environments, such as rivers and water quality. The hardware system consists of two main parts, namely, the transmitter unit and the receiver unit. The transmitter unit comprises a GPS Module, pH and temperature sensors, and ESP 32, while the receiver unit comprises a Web Server. The following is a block diagram of the system design:

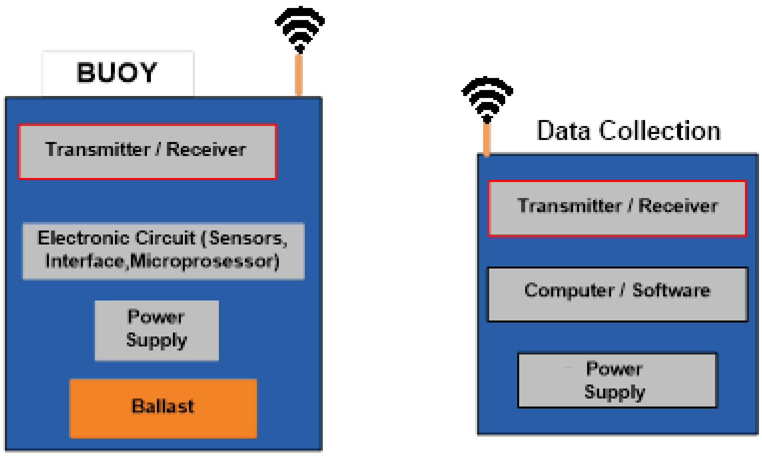

Figure 1 Block Diagram of the System

Figure 1 shows a system block diagram of a buoy equipped and placed in a river stream to follow the direction and speed of the water flow. While moving with the river, the data recorder on the buoy simultaneously takes pH and temperature measurements using the attached sensors. The data recorded by these recording devices is then stored and transmitted via modem (via WiFi network) to the data receiver in the laboratory. The data receiver will store the received data based on the time interval and position of the buoy. The results of this data analysis can provide information on river flow velocity, pH level, and water temperature at the river surface. Using buoys as floating devices on water is a simple and effective method for water quality monitoring. This buoy design is the most basic and essential element in the water quality monitoring process (Asha'ari & Ibrahim, 2022), as shown in Figure 2.

Figure 2 depicts a Smart Environment-based buoy that monitors river flow and water quality. The buoy has a diameter of about 30 cm and a height of 15 cm. Water quality sensors, such as pH and temperature, are mounted on the bottom. At the same time, GPS and other electronic components are placed on the top. The buoy also has vertical fins at the bottom to protect the sensors from physical impact. The water quality sensor used is a LOGOELE brand RS-485 Industrial pH and Temperature Transmitter Sensor, with a pH range of 0-14. pH comes from the word "p," which is the mathematical symbol for negative logarithm, and "H," which is the chemical symbol for the element Hydrogen. The formal definition of pH is the negative logarithm of Hydrogen ion activity, according to the equation "pH = - log [H^+]." pH can also be seen as quantitative information indicated by the degree of acidity or alkalinity associated with Hydrogen ion activity. If the concentration of H^+ is greater than the OH concentration, then the solution is acidic, with a pH value of less than 7.

Conversely, if the concentration of OH^- is more significant than H^+, then the solution is alkaline, with a pH value of more than 7. A neutral pH has a value of 7, which means that the solution has alkaline properties when the pH is more than seven. The pH is less than 7, indicating that the solution has acidic properties (Rufiyanto et al., 2020) and a temperature range of -20 to 80ºC, and requires a DC voltage supply of 12-24 V for GPS using Ublox Neo 6 GPS with an input voltage of 3.3 V or 5 V. The overall circuit of this device can be seen in Figure 1. The overall circuit of this device can be seen in Figure 3.

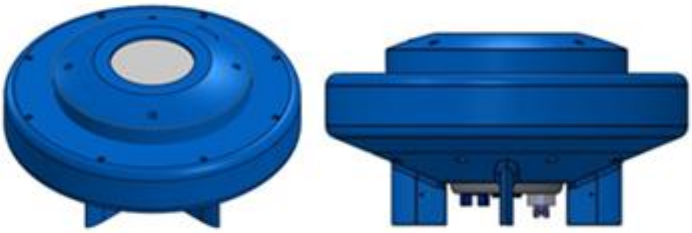

Figure 2 Three-dimensional (3D) design of the designed buoy

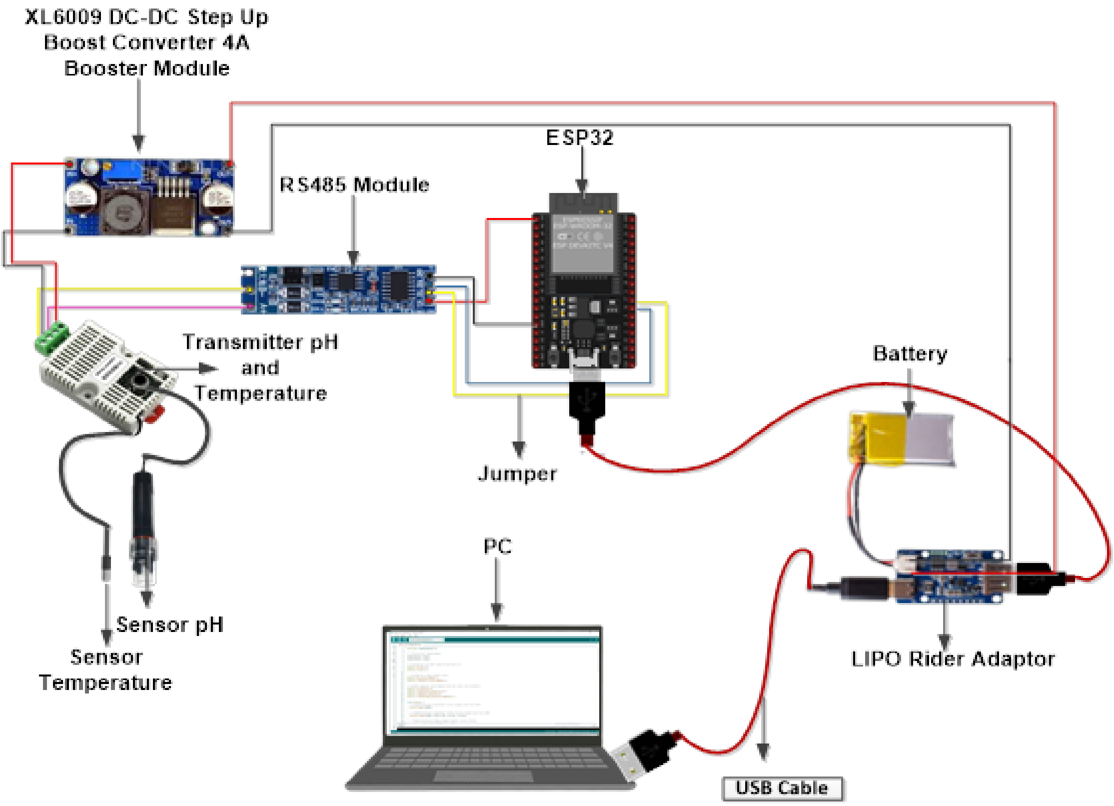

Figure 3 Overall System Devices

2.2 Software Design for River Flow and Water Quality Monitoring System using intelligent environment-based buoys

Arduino IDE software is required on the ESP32 board to write program code, which can be downloaded for free from the official Arduino website or other sources. After successfully downloading it, the next step is to install it on the computer. Program writing uses the Java or C/C++

programming language, depending on the module or microcontroller. The software needed in a real-time or IoT-based monitoring system is sent over a WiFi network using the MQTT protocol. The MQTT work system implements Publish and Subscribe data. In its application, the device will be connected to a Broker and has a particular Topic (Widja, 2018). The use of services from the Adafruit IO server specifically designed for IoT projects aims to display an interface for monitoring and storing data, allowing users to see real-time river discharge and water quality using a buoy. The flowchart of the software programming design can be seen in Figure 4.

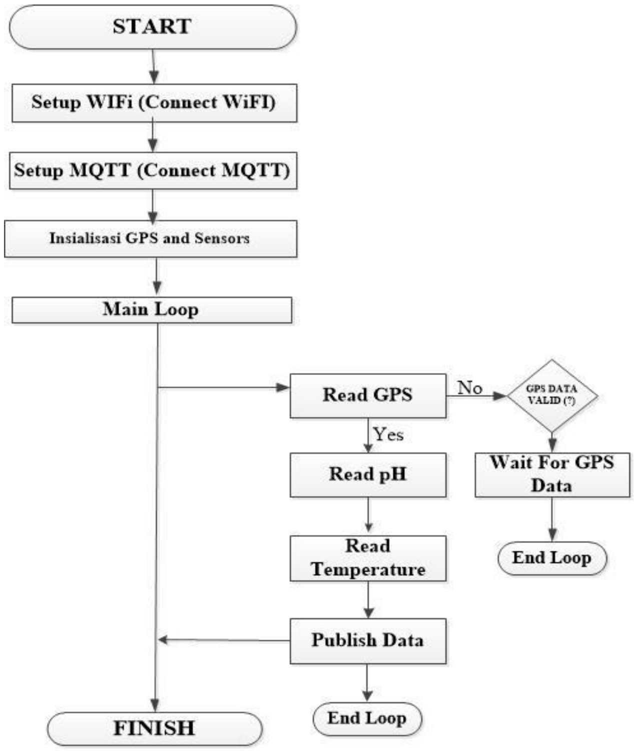

Figure 4 Flowchart of Program Design

2.3 Data Analysis

The system can collect structured valuable information for data analysis due to sensor devices, communication devices, data acquisition methods, and telemetry techniques (Moreno et al., 2019). By dividing data based on the type of measurement and monitoring, data analysis is a crucial way to understand the data. Direct measurement methods make measurements. (Fang et al., 2014), While in monitoring, an online approach is applied (Daskalakis et al., 2018). Direct measurement involves using specialized sensors to measure water quality parameters directly. For example, temperature is measured using temperature sensors (Kelly et al., 2013), while water pH is measured using pH sensors (Vijayakumar & Ramya, 2015). In the context of direct measurement, data analysis is a process used to evaluate the accuracy and precision of a measurement system. Accuracy refers to the extent to which the instrument reading is close to the actual value (Kirkup, 2019) and can be calculated by measuring the percentage error between the read value and the actual value (Jones, 1995). This percentage error can be calculated using Equation 1, while Equation 2 is used to calculate the percentage accuracy of the measuring instrument. *Yn* is the actual value on the comparator, and *Xn* is the value read on the measuring instrument.

$$\text{Percentage Error} = \left|\frac{Yn - Xn}{Yn}\right| x\ 100\% \qquad (1)$$

$$\text{Percentage Accuracy} = \left[1 - \left|\frac{Yn - Xn}{Yn}\right| x\ 100\%\right] \quad (2)$$

Conventional offline monitoring methods (Adeyemi et al., 2018) are no longer recommended. Instead, remote online monitoring, such as through IoT technology, is becoming a more advisable approach. In this case, IoT uses the MQTT protocol for data processing. MQTT speeds up and improves the reliability of the entire process, allowing any device around the world to connect easily. IoT (Internet of Things) has become very relevant and effective in the current era because it has overcome many problems. IoT can be used flexibly, anytime and anywhere it is needed (Abubaker et al., 2018). This approach allows the integration of different sensors to build a sensor network that collects data in real time for water quality evaluation (Yuan et al., 2018). Figure 5 shows the platform used as a Cloud database to simplify the data storage and analysis process.

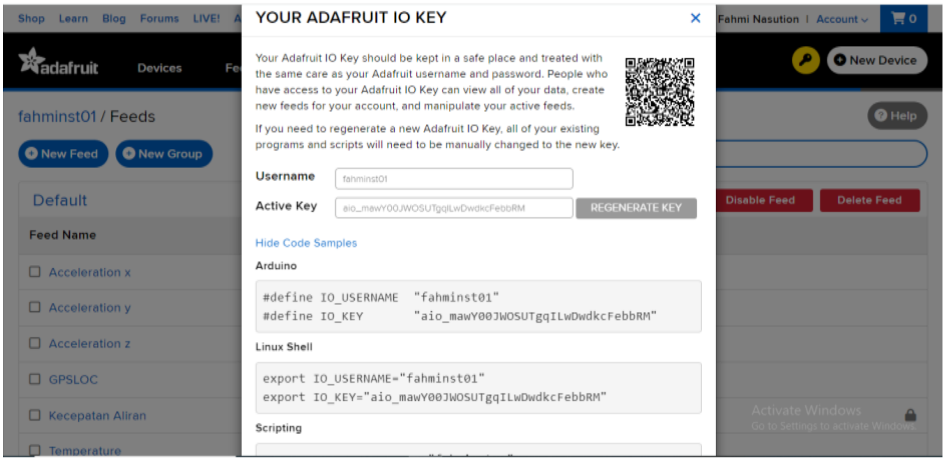

Figure 5 IoT platform

3. RESULTS AND DISCUSSION

3.1 GPS readings

GPS testing is done by connecting the GPS module to the ESP32. This aims to test the GPS data access needed to determine the position of the tool. If the GPS data reading produces an error and is not connected to WiFi, then the device's movement cannot obtain accurate position information. GPS can provide information about latitude, longitude, and speed.

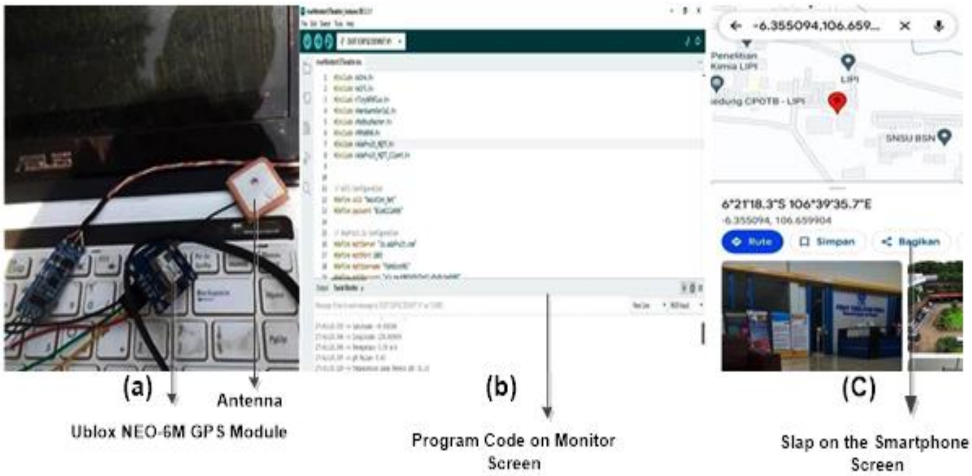

Figure 6 Testing the GPS Module (a) GPS Hardware Test (b) Program Test (c) Test with Maps

Figure 6 shows the connection and data access testing of the GPS module. This test aims to ensure that the data can be received correctly and the proper use of pins in conjunction with the ESP32 Microcontroller. The programming process of the GPS module is connected to the microcontroller through the Arduino IDE development environment. Part (a) of Figure 5 illustrates how the GPS module is connected to the microcontroller, which allows the user to set up and program the GPS module through the Arduino IDE development. This figure helps visualize the integration of the GPS module into a larger project or system. Part (b) includes the program created for the GPS module, while part (c) shows the coordinate points on the smartphone. The GPS module test data can be seen in Table 1.

Table 1. Ublox Neo-6M GPS Testing Results

No.	Coordinate System	Coordinate	
		GPS Ublox Neo-6M	**GPS Smartphone**
1.	Latitude	-6.355094	-6.355094
		-6.355094	-6.355094
		-6.355094	-6.355094
2.	Longitude	106.659904	106.659904
		106.659904	106.659904
		106.659904	106.659904

Table 1 describes the Ublox Neo-6M GPS module with accurate and consistent coordinate values, as displayed by the Maps application on the smartphone. The test location is in Serpong, South Tangerang, under the National Research and Invasion Agency, with coordinates 6.355094 for latitude and 106.659904 for longitude. The Ublox Neo-6M GPS module also showed good performance when used outdoors.

3.2 Testing the pH Sensor

pH is an essential parameter of most water monitoring devices (Yaroshenko et al., 2020). pH is a parameter that indicates the acidity or basicity of a liquid or solution. The pH level is determined using a scale of 0-14. pH 0 indicates a high level of acidity, and pH 14 indicates a high basicity level (Rufiyanto et al., 2020).

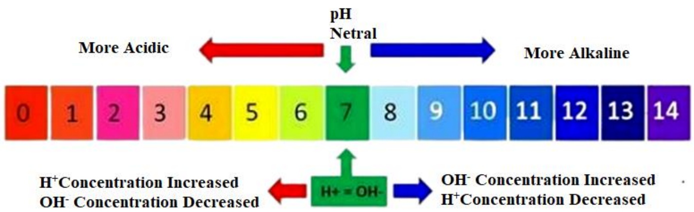

Figure 7 pH Scale

Figure 7 shows the pH scale used to measure the acidity or basicity of a solution. On the pH scale, seven is considered a neutral value, which means the solution is neither acidic nor basic. Solutions with a pH less than seven are considered acidic, with lower pH values indicating higher acidity. Conversely, solutions with a pH greater than seven are considered essential, with higher pH values indicating a higher level of basicity. Thus, the pH scale helps classify solutions based on their acidity or basicity, with the neutral value in the middle. The test includes samples of buffer powder solutions with pH levels of 4.00, pH 6.86, and pH 9.18. pH sensor testing is carried out on a pH buffer powder solution mixed with 250 ml of distilled water, and the pH value is recorded every 5 minutes for each data. The purpose of this test is to compare the results of the pH sensor data readings for ten different experiments with various pH buffer powder solutions that have been prepared, and the following graph shows a comparison of the pH sensor readings against time, as seen in Figure 8.

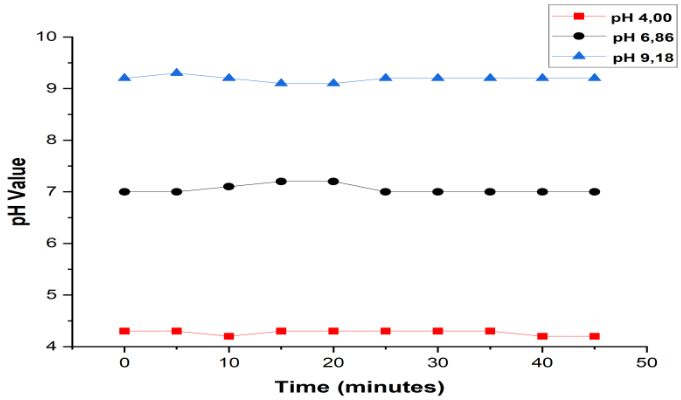

Figure 8 Comparison of pH value against time

Figure 8 displays a sensor graph showing the change in pH level against time. The blue dot shows the sensor's pH value at pH 9.18, which indicates that the pH sensor gives a reading close to the actual value in a solution with pH 9.18. The red dot shows the pH in a solution with pH 6.86, which indicates that the pH sensor gives a reading close to the actual value in a solution of pH 6.86. The black dot indicates the pH of the solution with pH 4.00, and the pH sensor gives a reading close to the actual value of the pH 4.00 solution. The graph shows that the higher the pH level of the solution, the closer to the standard value known by the pH sensor. This indicates that the pH sensor used in this test has a good level of accuracy, with an error rate of 3.3%. The 3.3% value was obtained by calculating the error in the buffer pH analysis involving ten samples. The analysis process produces errors with different values for each pH buffer tested. At pH 9.18, the error recorded was 0.45; at pH 6.86, the error reached 2.7; at pH 4, the error reached 6.75. After knowing the average error of each pH value, further calculations were carried out. The sum of the average errors of the three pH measurements was then divided by three to produce a value of 3.3%. This indicates that the 3.3% value results from the error normalization process in the buffer pH analysis performed at the three pH points.

3.3 Temperature Sensor Testing

Temperature measurement involves the transmission of heat energy from the object to the sensor, which is converted into an electrical signal. Heat conduction occurs when the contact sensor (probe) is in or above the object, which causes the sensing element to experience a change in temperature due to heat exchange with the object (Jacob, 2010). This test involves a comparison of a temperature sensor and a digital thermometer to measure the temperature of a distilled water sample. The temperature measurement graph on the distilled water sample using a digital thermometer and temperature sensor can be described as follows.

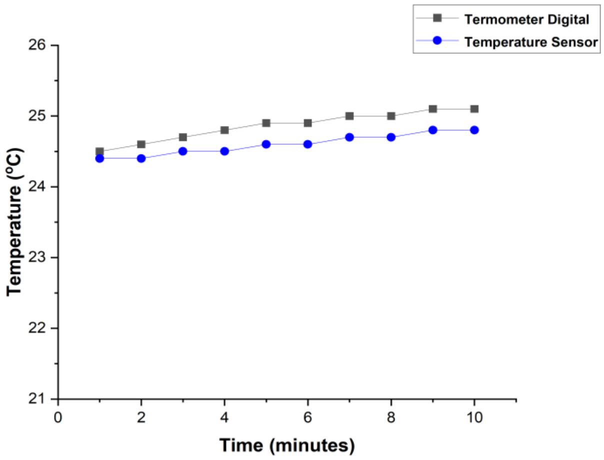

Figure 9 Comparison of Temperature against Time

Figure 9 shows the temperature measurement results on the distilled water sample. The graph has two lines: one black line represents the digital thermometer reading, and one blue line represents the temperature sensor reading. On the x-axis (horizontal), the test data from 1 to 10 indicates the time or order of data collection. On the y-axis (vertical), there are temperature values in degrees Celsius. This axis's range of temperature values is between 21-26 degrees Celsius. At the beginning of the graph (measurement sequence 1-4), both the digital thermometer (black line) and temperature sensor (blue line) readings are at almost the same or very close temperature values, indicating that both devices give similar results at those points. As time passes (measurement sequence 5-10), the temperature readings from both devices tend to increase gradually. This indicates that the temperature of the distilled water increases as time passes or certain conditions change in the test. Indoor air circulation is minimal, so the heat trapped in the room cannot be quickly circulated or dissipated. As a result, the air temperature in the room tends to be higher. The increase in air temperature around the room also affects the temperature of the distilled water. When the air temperature around distilled water is higher, heat is absorbed by the distilled water, causing the water temperature to rise. Thus, the temperature of uncontrolled indoor distilled water is affected by the surrounding environmental conditions that make the air temperature higher than desired. During the test, the difference between the readings of the digital thermometer and the temperature sensor remains minimal, indicating that the temperature sensor has good accuracy in measuring the temperature of the distilled water, follows temperature changes well, and ensures that the temperature measuring device works appropriately so that the error rate value obtained is 1.02%.

3.4 Monitoring Device Testing

The physical form of the device as a whole provides a visual description of the physical appearance of the system that has been designed. Figure 10 (a) shows the shape of the device consisting of a component storage box to protect the circuit components containing the main electronic components and batteries from being exposed to water, buoys, and sensors to measure water quality. Figure 10 (b), the designed circuit illustrates the interconnection of the interconnected main components to form a complete system. This design includes the various components required for the operation of the instrument.

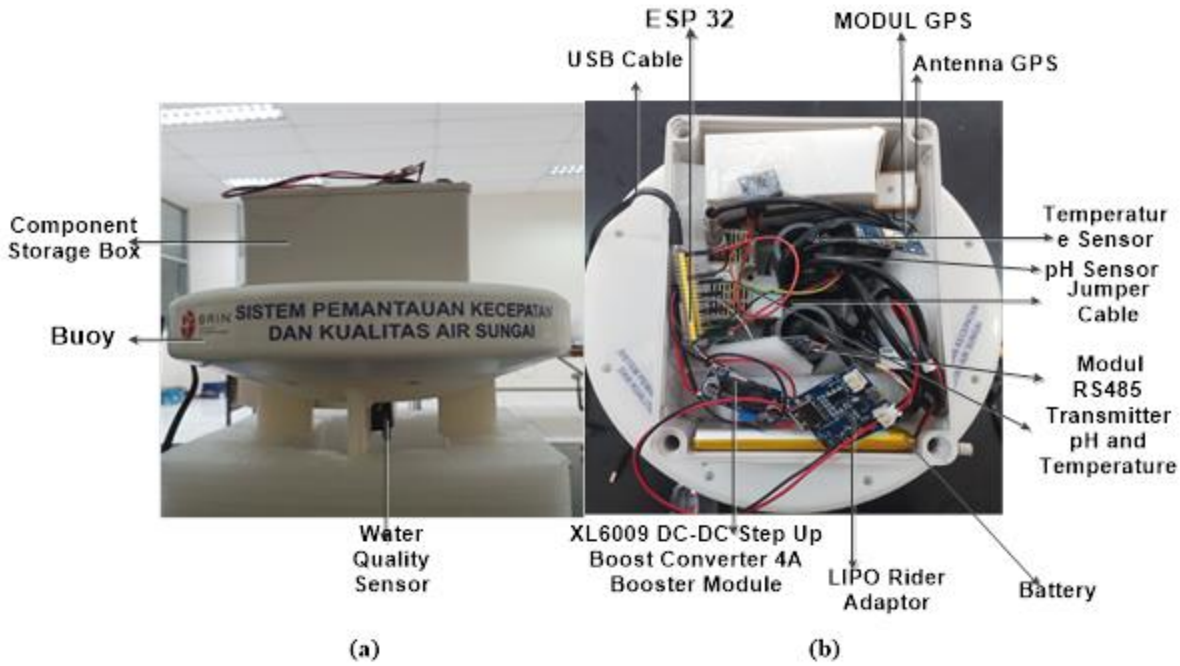

Figure 10 Overall Physical Form of the Tool (a) Buoy Shape Outer View (b) Buoy Shape Inner View

The river water monitoring system was tested to evaluate its performance according to the planned design. Figure 11 illustrates the buoy's position on the river bank, ensuring it does not sink and can transmit measurement data to the Cloud. The buoy was tested in a river with stable water flow in the Puspiptek Serpong complex on August 08, 2023. Testing buoys in rivers with stable conditions aims to test and evaluate the performance of buoys in river conditions with stable water flow. The buoy is placed in the river to measure water quality parameters to ensure that the buoy is functioning correctly, including resistance to changes in water flow velocity, stability, and measurement accuracy.

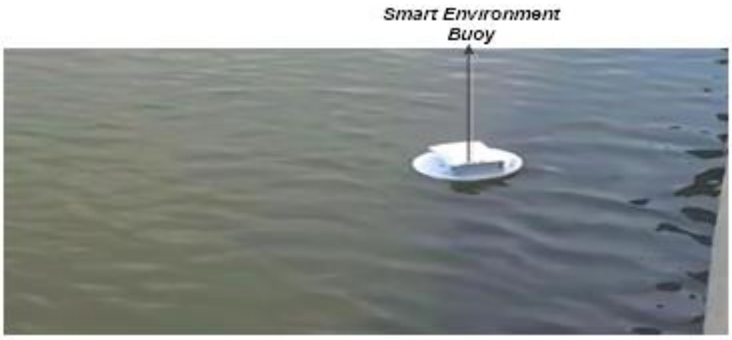

Figure 11 River Buoy Trial

The data transmission results in the Cloud can be easily accessed through the display from the Adafruit platform. Figure 12 includes device position, pH, temperature, and flow velocity data. The Adafruit platform provides an informative and structured display, Enables users to quickly and accurately monitor all relevant parameters in collecting data received from sensors and related devices that can be better accessed and analyzed, and Enables more informed and efficient decision-making in managing the system or process being monitored.

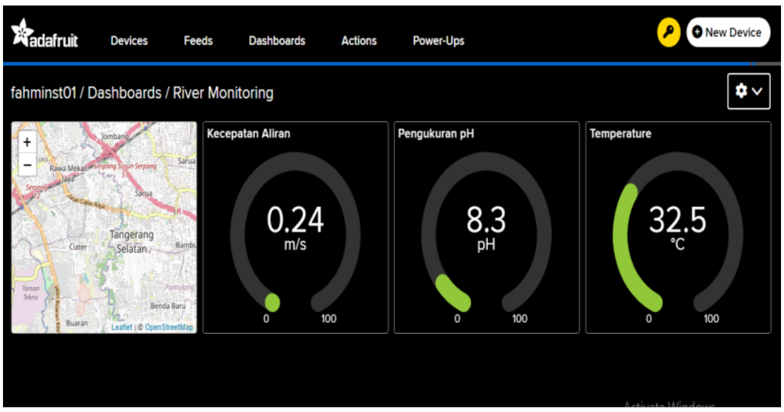

Figure 12 Display of Buoy to Cloud Measurement Results

Buoy to cloud display based on this study's design, testing, and measurement results. The designed system successfully sends and processes monitoring data into the database. Buoys equipped with equipment are inserted into the river flow according to the direction and speed of the flow. While being carried by the water current, the data recording device simultaneously measures the buoy's position from the GPS module, temperature, and pH through the installed sensors. The developed tool has accurate GPS coordinate values, with the GPS coordinate data reader device using a GPS module that is in the same position when the GPS coordinates from Google Maps are taken. In addition, there is a percentage error of 3.3% for the pH sensor and 1.02% for the temperature sensor measurement results. As a future direction, the suggestions are using the latest sensors to detect various other quality parameters, wireless communication standards for better communication, and IoT to make a better system for water quality monitoring so water resources can be made safe with a fast response.

4. CONCLUSION

Buoy to Cloud display based on the design, testing, and measurement results in this study successfully sends and processes monitoring data into the database. Buoys equipped with equipment are inserted into the river flow according to the direction and speed of the flow. While being carried by the water current, the data recording device simultaneously measures the buoy's position from the GPS module, temperature, and pH through the installed sensors. The developed tool has accurate GPS coordinate values, with the GPS coordinate data reader device using a GPS module that is in the same position when the GPS coordinates from Google Maps are taken. In addition, there is a percentage error of 3.3% for the pH sensor and 1.02% for the temperature sensor measurement results. Thus, the system we have developed has the potential to be used as a substitute for field sampling-based river water quality monitoring systems. As a future development, the suggestions are using the latest sensors to detect various other quality parameters, wireless communication standards for better communication, and IoT to make a better system for water quality monitoring so water resources can be made safe with a fast response.

ACKNOWLEDGEMENT

Thanks to the Research Center for Photonics, National Research and Innovation Agency (BRIN), BJ.Habibie Science and Technology Park for supporting this research.

REFERENCE

Abubaker, A., Thomas, T., & Begum, S. (2018). Testing Water Quality by an efficient MQTT algorithm using an IOT approach. *International Journal of Scientific & Engineering Research*, *9*(4), 64–67.

Adeyemi, O., Grove, I., Peets, S., Domun, Y., & Norton, T. (2018). Dynamic modelling of lettuce transpiration for water status monitoring. *Computers and Electronics in Agriculture*, *155*(September), 50–57. https://doi.org/10.1016/j.compag.2018.10.008

Ajith Jerom, B., & Manimegalai, R. (2020). An IoT Based Smart Water Quality Monitoring System using Cloud. *International Conference on Emerging Trends in Information Technology and Engineering, Ic-ETITE 2020*, 1–7. https://doi.org/10.1109/ic-ETITE47903.2020.450

Akbar dkk, S. Al. (2019). Online Monitoring Kualitas Air Waduk Berbasis Thingspeak. *Tranmisi Undip*, *21*(4), 109–115.

Asha'ari, M. I., & Ibrahim, A. I. (2022). Wireless Water Quality Monitoring System. *2022 IEEE 9th International Conference on Underwater System Technology: Theory and Applications, USYS 2022*, 1–8. https://doi.org/10.1109/USYS56283.2022.10072669

Damayanti, A. A., Wahjono, H. D., & Santoso, A. D. (2022). Pemantauan Kualitas Air Secara Online dan Analisis Status Mutu Air di Danau Toba, Sumatera Utara. *Jurnal Sumberdaya Alam Dan Lingkungan*, *9*(3), 113–120. https://doi.org/10.21776/ub.jsal.2022.009.03.4

Daskalakis, S. N., Goussetis, G., Assimonis, S. D., Tentzeris, M. M., & Georgiadis, A. (2018). A uW Backscatter-Morse-Leaf Sensor for Low-Power Agricultural Wireless Sensor Networks. *IEEE Sensors Journal*, *18*(19), 7889–7898. https://doi.org/10.1109/JSEN.2018.2861431

Fang, S., Xu, L. Da, Zhu, Y., Ahati, J., Pei, H., Yan, J., & Liu, Z. (2014). An integrated system for regional environmental monitoring and management based on internet of things. *IEEE Transactions on Industrial Informatics*, *10*(2), 1596–1605. https://doi.org/10.1109/TII.2014.2302638

Gokulanathan, S. (2019). A GSM Based Water Quality Monitoring System using Arduino. *Shanlax International Journal of Arts, Science and Humanities*, *6*(4), 22–26.

Herschy, R. W. (2012). Water quality for drinking: WHO guidelines. In *Encyclopedia of Earth Sciences Series* (pp. 876–883). https://doi.org/10.1007/978-1-4020-4410-6_184

Masykur, H.Z., Amin, B., Jasril, J., & Siregar, S. H. (2018). Analisis Status Mutu Air Sungai Berdasarkan Metode STORET Sebagai Pengendalian Kualitas Lingkungan (Studi Kasus: Dua Aliran Sungai di Kecamatan Tembilahan Hulu, Kabupaten Indragiri Hilir, Riau). *Dinamika Lingkungan Indonesia*, *5*(2), 84. https://doi.org/10.31258/dli.5.2.p.84-96

Jacob, F. (2010). Modern Sensors. In *Springer* (4th ed., Vol. 6, Issue August). Springer New York Heidelberg Dordrecht London. https://doi.org/10.1007/978-1-4419-6466-3

Jan, F., Min-Allah, N., & Düştegör, D. (2021). Iot based smart water quality monitoring: Recent techniques, trends and challenges for domestic applications. *Water (Switzerland)*, *13*(13), 1–37. https://doi.org/10.3390/w13131729

Jones, L. D. (1995). *Electronic Instruments and Measurements* (Second). Prentice-Hall International Editions. https://doi.org/10.1038/166222a0

Kelly, S. D. T., Suryadevara, N. K., & Mukhopadhyay, S. C. (2013). Towards the implementation of IoT for environmental condition monitoring in homes. *IEEE Sensors Journal*, *13*(10), 3846–3853. https://doi.org/10.1109/JSEN.2013.2263379

Kementerian Lingkungan Hidup dan Kehutanan Republik Indonesia. (2017). *Petunjuk Teknis Restorasi Kualitas Air Sungai* (Issue 021). http://ppkl.menlhk.go.id/website/filebox/270/180530101715Petunjuk Teknis Restorasi Kualitas Air Sungai.pdf

Kirkup, L. (2019). Experimental Methods for Science and Engineering Students: An Introduction to the Analysis and Presentation of Data. In *Experimental Methods for Science and Engineering Students: An Introduction to the Analysis and Presentation of Data*. https://doi.org/10.1017/9781108290104

Lakshmikantha, V., Hiriyannagowda, A., Manjunath, A., Patted, A., Basavaiah, J., & Anthony, A. A. (2021). IoT based smart water quality monitoring system. *Global Transitions Proceedings*, *2*(2), 181–186. https://doi.org/10.1016/j.gltp.2021.08.062

Menteri Kesehatan Republik Indonesia. (2017). Peraturan Menteri Kesehatan Republik Indonesia Nomor 32 Tahun 2017 Tentang Standar Baku Mutu Kesehatan Lingkungan Dan Persyaratan Kesehatan Air Untuk Keperluan Higiene Sanitasi, Kolam Renang, Solus Per Aqua dan Pemandian Umum. In *Peraturan Menteri kesehatan Republik Indonesia* (pp. 1–20).

Moreno, C., Aquino, R., Ibarreche, J., Pérez, I., Castellanos, E., Álvarez, E., Rentería, R., Anguiano, L., Edwards, A., Lepper, P., Edwards, R. M., & Clark, B. (2019). Rivercore: IoT device for river water level monitoring over cellular communications. *Sensors*, *19*(1), 2–5. https://doi.org/10.3390/s19010127

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 (Switzerland)*, *12*(2). https://doi.org/10.3390/w12020510

Pasika, S., & Gandla, S. T. (2020). Smart water quality monitoring system with cost-effective using IoT. *Heliyon*, *6*(7), e04096. https://doi.org/10.1016/j.heliyon.2020.e04096

Pemerintah Republik Indonesia. (2011). Peraturan Pemerintah Republik Indonesia Nomor 38 Tahun 2011 tentang Sungai. In *Peraturan Pemerintah Republik Indonesia Nomor 38 Tahun 2011 tentang Sungai*. (p. 24). https://www.hukumonline.com/pusatdata/detail/v2/lt4e4241b91b57a/peraturan-pemerintah-nomor-38-tahun-2011

Putro, E. Y., & Suryono. (2017). Rancang bangun sistem sensor nirkabel untuk memantau kecepatan dan arah aliran. *Youngster Physics Journal*, *6*(1), 32–39.

Roshidi, H., & Thirunavakkarasu, P. (2021). The Development of Water Quality Monitoring System at Dam. *Journal of Engineering Technology*, *9*(1), 82–85.

Rufiyanto, A., Abdilah, G. S., & Purwaningrum, S. D. (2020). Rancang Bangun Sistem Pengukuran pH dan Kekeruhan Air Berbasis Mikrokontroller Atmega 328. *Jurnal Neo Teknika*, *6*(1), 8–17.

Soeboer, D. A., Iskandar, B. H., Jaya, I., Imron, M., Psp-fpik-ipb, P. T., Psp-fpik-ipb, D., & Itk-fpik-ipb, D. (2018). Design and Construction of The Buoy for Detecting Surface Current Movement Using GPS. *Albacore*, *2*(3), 263–277.

Vijayakumar, N., & Ramya, R. (2015). The real time monitoring of water quality in IoT environment. *ICIIECS 2015 - 2015 IEEE International Conference on Innovations in Information, Embedded and Communication Systems*, 1–5. https://doi.org/10.1109/ICIIECS.2015.7193080

Widja, I. B. P. (2018). Sistem IoT Berbasis Protokol MQTT Dengan Mikrokontroler ESP8266 dan ESP32. *SNATIF-Fakultas Teknik Universitas Muria Kudus*, 329–336.

Yaroshenko, I., Kirsanov, D., Marjanovic, M., Lieberzeit, P. A., Korostynska, O., Mason, A., Frau, I., & Legin, A. (2020). Real-time water quality monitoring with chemical sensors. *Sensors (Switzerland)*, *20*(12), 1–22. https://doi.org/10.3390/s20123432

Yuan, Y., Feng, S., Alahi, M. E. E., Nag, A., Afsarimanesh, N., Zhang, H., & He, S. (2018). Development of an internet of things based electrochemical microfluidic system for free calcium detection. *Applied Sciences*, *8*(8). https://doi.org/10.3390/app8081357