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Design and Development of Water Quality Monitoring and Weather Station System Based on Industrial Sensors Using Modbus RS458 Protocol

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Abstract

River water quality is typically monitored using sampling methods. This approach makes detecting water pollution challenging owing to the limited sampling time. Another factor influencing water quality is weather, which can be addressed by incorporating weather station sensors as corrective tools. The collected data were processed and visually displayed to make the important information easily interpretable. The water quality parameters measured in this study included Electrical Conductivity (EC), temperature, Total Dissolved Solids (TDS), salinity, pH, turbidity, Dissolved Oxygen (DO), and saturation. The weather parameters measured by the system included wind speed, wind direction, air temperature and humidity, atmospheric pressure, rainfall, and solar radiation. The system's capabilities include data transmission via cellular networks, data backup using an SD card, and industrial sensors with IP (Ingress Protection) standards that utilize the Modbus RS485 protocol. The study followed the Software Development Life Cycle (SDLC) or waterfall method to ensure system readiness and durability in real-world environments. The Modbus RS485 protocol allows multiple sensors to share a single cable line, resulting in a more efficient and less complex wire arrangement. These findings highlight the necessity of separating sensor lines based on parity type and baud rate for each sensor, enabling simultaneous readings in subsequent operations.

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1. Introduction

The rate of river pollution in Indonesia is high. BPS (Central Bureau of Statistics) noted that in 2021, the number of polluted rivers in Indonesia reached 46%, 32% of which were heavily polluted, 14% were moderately polluted, and 8% were lightly polluted. Some rivers on which many people depend, such as the Citarum River, have special regulations issued by the president through Presidential Regulation (Perpres) No. 15 of 2018 concerning the acceleration of pollution control and damage to the Citarum River watershed. Based on a Press Release of the Ministry of Environment and Forestry (KLHK), Number SP. 651/HUMAS/PP/HMS.3/11/2018, the Cisadane River that passes through the city of Bogor to Tanggerang is also heavily polluted, dominated by domestic pollutants

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(83.99 %), followed by industrial pollutants (8.39%), livestock pollutants (3.94%), agricultural pollutants (2.46%), infrastructure and services pollutants (0.71%), and fishery pollutants (0.51%).

River water quality parameters can change as the weather changes (Bhurtun et al., 2019). Over a longer period, climate change also triggers changes in the surface water quality (Ivanovsky et al., 2016). The water quality parameters studied included dissolved oxygen (DO), pH, conductivity, and nitrate and phosphate levels. Some studies have used water clarity, conductivity, temperature, and hardness parameters to estimate the number of E. coli (Panidhapu et al.,2020). Changes in water quality also showed a close correlation with weather after further analysis (Safieh et al.,2020). In this study, weather parameters, such as atmospheric pressure, evaporation, wind speed, radiation, and rain intensity, and water parameters, such as clarity, pH, color, and E. coli bacterial content, were investigated. The design an Internet of Things (IoT)-based monitoring system for rivers was carried out by (Singh et al.,2022) by measuring approximately 17 water quality parameters sent using GSM transmission media.

Another transmission that can be utilized to transmit data over long distances is radio frequency or Lora (Sant.s et al., 2019), Lora has reincludens that have been divided into several classes, in this case class B can be implemented (Elbsir et al.,2022). Nakamura conducted research on Lora transmission in 2022. However, the disadvantage of this radio transmission is that the signal range is not as large as that of GSM (Botero-Valencia et al.,2022). The combination of water quality sensors and weather stations will complement each other to detect anomalous changes in water quality parameters. The detection of anomalies at high frequencies (Shi et al., 2018) could be performed with good accuracy, reaching 0.98. However, the addition of weather parameters as supporting values requires further research, particularly for pollutant detection (Yoshioka et al., 2016). Pollutants in river water can also be detected from upstream to downstream (Meyer et al., 2019). This research, which discusses a monitoring system built from industrially certified components, is a novelty that will be raised. The analysis was provided in the form of graphs aimed at reading anomalies in water quality values and weather parameters (Jabbar et al., 2022).

2. Materials and Methods

2.1 Materials and Tools

In addition to Internet connection services, the equipment needed in this research was divided into 2, namely the hardware and software. The hardware used met the Inggress Protection (IP) test. The sensors that were used are listed in Table 1.

Table 1. Hardware.

Item Name	Quantity	Description
Controllino MAXI	1 pcs	Controlling the system on the device
Soldering device	1 pcs	To connect the cable
GSM module	1 pcs	Transmitting data to the internet
Connector sensor 4 pin	5 pcs	Connecting sensors to the system
Solar panel 150wp	1 pcs	Battery charging power source
Solar panel charger controller	1 pcs	Battery charge controller
Baterai 18650 (3100mAh)	8 pcs	Backup power storage
RS485 to ttl converter	1 pcs	Convert RS485 signal
Laptop (Intel Core i5)	1 pcs	To program the tool
Waterproof Box outdoor	1 pcs	Tool storage area
AWG 16 Cable	2 meters	Connecting electric current
Pipe PVC 4 inch	1 meters	As a sensor holder
Sensor RIKA EC RK500-13	1 pcs	Sensor *electrical conductivity*
Sensor RIKA PH RK500-12	1 pcs	Acidity or PH sensor
Sensor RIKA *turbidity* RK-500-07	1 pcs	Clarity sensor
Sensor RIKA DO RK500-04	1 pcs	Dissolved oxygen sensor
Weather Sensor RIKA RK900-11	1 pcs	Weather sensor

The hardware used in the device was customized such that it could communicate with each other. The factors considered included the protocol, operating power, radio frequency, dimensions, and battery capacity. More details of the device can be seen in Table 2. Thus, the selection of the right device can minimize obstacles in the integration process.

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Table 2. Hardware Image.

Item name	Image
Controllino MAXI	
Soldering device	
GSM module	
Connector sensor 4 pin	
Solar panel 150wp	
Solar panel charger controller	
Baterai 18650 (3100mAh)	
RS485 to ttl converter	

Continue

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Item Name	Image
Laptop (Intel Core i5) Waterproof Box outdoor	
Box outdoor anti air	
AWG 16 Cable	
Pipe PVC 4 inch	
Sensor RIKA EC RK500-13	
Sensor RIKA PH RK500-12	
Sensor RIKA *turbidity* RK-500-07	
Sensor RIKA DO RK500-04	
Weather Sensor RIKA RK900-11	

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The water quality sensor and weather station were manufactured by RIKA Electronic Co., Ltd. RIKA is a sensor manufacturing company that has 90001:2015 CE and RoHS certifications and has passed the supplier assessment test by TUV Nord. All sensors used in this research have an RS485 Modbus interface and are read by the MAXI microcontroller. The controllino MAXI device was certified as UL 61010-1:2010, CSA-C22.2 No. 61010-1, UL 61010-2-201, CSA-C22.2 No. 61010-2-201, CE, RoHS, and REACH (*Registration, Evaluation, Authorization, and Restriction Chemical*). The certified device is powered by a 12,000 mAh battery for backup power at night, whereas during the day, the system is powered by a solar panel. Separate weather station sensor data were read using the RS485 converter module, whereas the water quality sensor was read directly by the microcontroller through the RS485 interface. The microcontroller and electronic devices are placed in a waterproof box and connected to the sensor via a removable connector. The software used in this research was Arduino IDE, Microsoft Edge, Modbuspool, and Microsoft Word.

The parameters measured in water quality research are PH, electrical conductivity (EC), salinity, total dissolved solids (TDS), dissolved oxygen (DO), clarity/turbidity, temperature, and saturation. The data parameters to be measured by the weather station sensor were wind speed, wind direction, air temperature, air humidity, air pressure, rainfall, and solar radiation.

2.2 Research Methods

The design and construction of the tool began with the problem identification process, as shown in Figure 1. Subsequently, sensor device criteria were designed to solve the identified problems. The process continues with the functional and structural design, and the important features and working structure of the tool on the sensor device are arranged. The design continues by identifying the right material for the construction of this sensor, which is important for ensuring that the sensor device can last for a long time outdoors. The next step is the simulation and calibration of the device, which are performed if the sensor device has not passed the calibration stage during its production. The purpose of this calibration was to improve the accuracy of the sensor readings. After the sensor goes through the calibration stage, the sensor will then be installed for the overall prototype of the device, after which structural and functional tests will be carried out. At the structure and functional test stage, if all functions have run well, a performance test is performed; if the structure and function test results do not run well, an evaluation is performed on the sensor device.

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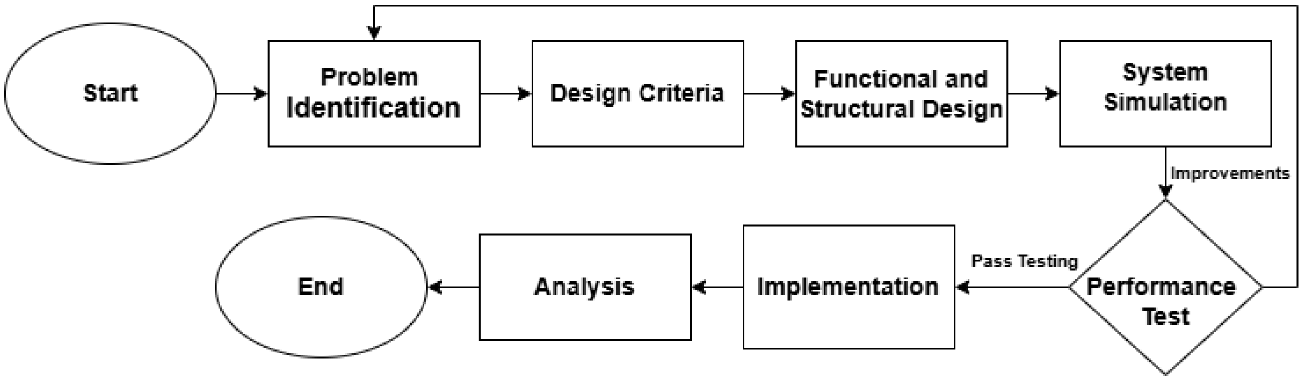

Figure 1. Flowchart of the Research Methods.

Performance testing and field implementation were performed after the sensor device had functioned properly. Finally, the data from the device were analyzed. The design criteria for the device to be built are as follows.

1. The sensor device can be charged through the photovoltaic that has been installed in the PV system.
2. Water quality parameters included electrical conductivity (EC), temperature, total dissolved solid (TDS) salinity, PH, turbidity/clarity, dissolved oxygen (DO), and saturation.
3. It can read weather parameters, such as wind direction, wind speed, air temperature, air humidity, air pressure, rainfall, and solar radiation.
4. Send data from sensors to the Internet using lora and gsm transmissions as backups.

The reading parameters were displayed using a web interface. Thus, all the above criteria become the benchmark for the tool to be built in this study.

2.3 Identification of Design Criteria

The selection of sensors and systems was adjusted according to the needs and the measurement environment. The values listed in the measurements by the Central Bureau of Statistics (BPS) are used as a reference for the value limits of each weather parameter. Technically, this weather sensor must be able to pass through hot and rainy situations in tropical countries, such as Indonesia. The certification that the device must have been at least IP54 (Inggress Protection), which allows the sensor to withstand dust and water splashes in various directions. This criterion is required to accommodate heavy rainstorms, so that water can enter from various directions. The criteria used for weather sensors are listed in Table 3.

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Table 3. Weather Sensor Criteria.

Parameter	Criteria	BPS Value
Protocol	ModbusRS485/Analog/Digital	
Power	3v, 5v, 12v (< 3W)	
Protection	IP *Certificate* IP 54	
Weight	< 500 gram	
Wind speed	0-15 m/s	0-15m/s
Wind direction	(0-360 degree)	0-360 degree
illuminasi	0-15.000 Lux	0-1500Lux
Rainfall	5000 mm	Highest 4627,40mm
temperature	0-45^{o}C	9-36.7 ^{o}C
Humidity	0-100%	30-100%
Air pressure	800-1100hpa	1008- 1011,6hpa

The protocol used in this study was the RS485 Modbus, which is based on the use of sensors that are more than one unit. The RS485 protocol is serial, and can accommodate up to 32 devices. This protocol makes the use of cables in the system more efficient and simple. Other parameters, such as the power of the sensor, must be low so that the power consumption of the battery can last for a long time. The 12-volt DC current was chosen for safety reasons, and the system will directly interact with water so that the AC current is considered more dangerous for research activities. The parameter values measured by the weather station must be adjusted to the adjusted interval, and the specifications of the water quality sensor must be adjusted to the needs and environment in which the sensor is installed later. The Central Statistics Agency was used as a reference was the measurement of the Central Statistics Agency (BPS). The values of each parameter in each region are different; therefore, the values used as references are the highest and lowest values that are close to the sensor specification limits. Using this method, the scale variation in the sensor readings was determined. The water quality sensor criteria are listed in Table 4.

The special requirements that must be met for water quality sensors are the waterproofing ability and service life of the sensors. A sensor with a material that is resistant to water and that has a certificate of use is required. The appropriate waterproof certification for this requirement is IP68 (Inggress Protection), which allows the sensor device to be resistant to fine dust and survive when permanently immersed in water. The protocol used was the same as that used for the weather station sensor RS485 Modbus.

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Table 4. Water Quality Sensor Criteria.

Parameter	Needs
PH	0-14
EC	0-10,000us/cm
Salinity	0-100,000mg/L
TDS	0-2000ppm
DO	0-20mg/L
Clarity	0-3000NTU
Temperature	0-50 ^oC
Saturation	0-100%

2.4 Functional Design

The function of the tool to be built is to measure the water quality and weather based on predetermined parameters. The functions included the following.

1. A water quality sensor device can measure electrical conductivity (EC), temperature, total dissolved solids (TDS), salinity, PH, turbidity/clarity, dissolved oxygen (DO), and oxygen saturation.
2. The weather station sensor device can measure wind speed, wind direction, temperature, humidity, air pressure, rain, and solar radiation.
3. The device can transmit data and can be accessed via the internet.
4. A chargeable battery with photovoltaic power was used as the primary source of electrical energy.
5. The system was shut down in the event of a short circuit or a voltage below 12v.
6. It has a data backup system stored in SD card memory.

2.5 Power Requirement Analysis

The battery capacity requirements are adjusted according to the power used in the system. Power was used for the sensors, microcontrollers, and I/O devices in the system. Battery capacity is influenced by the length of the measurement time and the time interval between measurements. If the battery capacity is too small, it will result in limited operating time. If the battery capacity is too large, the charging process will be long; therefore, it must be balanced with the size of the photovoltaic.

Each parameter was measured serially for each sensor. The measurement interval was 5 min, and the total time required for all sensors to provide feedback was 10 s. If the observation is performed for 24 h, the daily power calculation can be seen in Table 5. Miscellaneous values to accommodate the energy wasted as heat were assumed to be 20mAh.

It is known that the total power demand per day is 138.88Wh with 24-hour measurements without intervals. This calculation was based on the requirement of an adjustable interval period. This allowed

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all the devices to be active for 24 h. Thus, if there is no photovoltaic charging process during the 24-hour period, the battery must still be able to activate the system.

Table 5. System Components.

Component Name	Total	Power (W)	Time (Jam)	Current (A)	Daily Power Consumption (Wh)
Modem GSM (5V)	1	2.5	24	0.5	60
Weather Station (12V)	1	1.7	24	0.142	40
DO Sensor (12V)	1	0.4	24	0.034	9.6
TDS Sensor (12V)	1	0.2	24	0.017	4.8
EC/Salinity Sensor (12V)	1	0.2	24	0.017	4.8
PH Sensor (12V)	1	0.2	24	0.017	4.8
Turbidity Sensor (12V)	1	0.2	24	0.017	4.8
Controllino MAXI (12V)	1	1.68	24	0.14	40.32
Other	1	0.24	24	0.02	5.76
Total		7.32		175.68	175.68

Each parameter was measured serially for each sensor. The measurement interval was 5 min, and the total time required for all sensors to provide feedback was 10 s. If the observation is performed for 24 h, the daily power calculation can be seen in Table 5. Miscellaneous values to accommodate the energy wasted as heat were assumed to be 20mAh.

It is known that the total power demand per day is 138.88Wh with 24-hour measurements without intervals. This calculation was based on the requirement of an adjustable interval period. This allowed all the devices to be active for 24 h. Thus, if there is no photovoltaic charging process during the 24-hour period, the battery must still be able to activate the system.

2.6 Battery Capacity Requirement Analysis

Based on the detailed specifications of each component in the system, and assuming that the system operates 24 h without charging, the battery capacity can be calculated as follows:

$$Battery\ Capacity\ (Ah) = \frac{Daily\ Power(Wh)}{Voltage(V)} \quad (1)$$

The battery capacity required to handle a tool that is active for 24 hours is 12.2 Ah or 12,200 mAh. Based on this value, if researchers string 18650 Li-ion batteries with a capacity of 3,100mAh, they must be arranged in parallel as many as four pieces to represent one battery cell. Thus, the capacity obtained was 12,400 mAh, which is close to the requirements of the system being built.

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2.7 Analysis of system flow requirements

The current required in this monitoring system is based on sensor components, microcontrollers, and supporting I/O such as converter modules. The components used are listed in Table 4, with a total current requirement of 0.904 A. The battery used must be able to supply a current of 0.904A with a voltage of 12v or more. Based on technical information, the Sony VTC6 battery has a maximum discharge current of 10A. This means that the system current requirement is still below the maximum limit and the battery used can accommodate the system needs.

2.8 Battery Voltage Requirement Analysis

The battery voltage of the system was adjusted according to the electronic components used. Based on Table 4, the highest voltage used by the components was 12v, while the lowest voltage was 5v. Each 18650 Li-ion battery has a voltage of 3.7 to 4.2v, so at least four batteries are required in series to obtain a voltage of more than 12v. The total battery voltage after being arranged is between 14.4v when empty and 16.8v when full. If the battery voltage decreases to less than 13.8v, the device automatically shuts down to avoid damage to the battery, because it is used beyond its capacity.

2.9 Photovoltaic Demand Analysis

The photovoltaic or solar panel required in the system should support fast charging, and the battery should be fully charged with less than 2 h of irradiation within one day. As the current generated by photovoltaics is low (Ayadi et al. 2022). This is due to several factors, one of which is the change in the value of solar radiation caused by cloud movement or atmospheric phenomena. Based on the BPS data for 2020 and 2021, the smallest average sunshine in Bogor District was 12.1%. The smallest value was obtained during the rainy season in February 2021. This means that for a duration of 10 h, from 7:00 am to 5:00 pm, the irradiation duration was no longer than 1 h or 30 min. The capacity of the battery used was 12,400mAh (C) and the voltage was 12v. to charge the battery fully, which can be calculated as follows:

$$\text{Required current (A)} = \frac{\text{Battery capacity (Ah)}}{\text{Charge time (h)}} \quad I = \frac{C}{t} \tag{2}$$

The current value obtained to fully charge the battery for 1.5 hours is 8.27 A. Thus, the photovoltaic specifications used must produce a current of at least 8.27 A so that the battery can be fully charged in just 1.5 hours. The assembled battery has a maximum voltage of 16.8v, whereas the voltage required for the charging process to occur must be higher than 16.8v. If the charging voltage is 18v and the required current is 8.27 A, then the required photovoltaic power capacity is 148.86 WP. Thus, the photovoltaic used in the system is close to 148.86WP (watt peak) or in the market available with a capacity of 150 WP.

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3 Results and Discussion

3.1 Hardware Design

The hardware design begins by reading the value of the sensor using a microcontroller. The identity of each sensor is seen from the sensor's slave ID, which is a code used as a marker between the sensors. Each sensor must have a different ID, which is used during the value request process of the sensor. Further details are presented in Table 6.

Table 6. Sensor Function Test Results.

No	Sensor	Parameter	Unit	Data reading
1	EC RK500-13	EC (*electric conductivity*)	mS/cm	Read
2		Temperature	celcius	Read
3		TDS (*total dissolved solid*)	PPM	Read
4		Salinity	PPM	Read
5	PH RK500-12	PH		Read
6	Turbidity RK-500-07	Clarity	NTU	Read
7	RK500-04	DO (*dissolved oxygen*)	mg/L	Read
8		Saturation	%	Read
9	RK900-11	Wind direction	degree	Read
10		Wind speed	m/s	Read
11		Air temperature	celcius	Read
12		Air humidity	%	Read
13		Air pressure	hpa	Read
14		Rainfall	mm/h	Read
15		Solar radiation	W	Read

The monitoring system hardware was housed in an acrylonitrile butadiene styrene (ABS) plastic compartment box with a lid. The compartment had dimensions of 190 mm × 290 mm × 140 mm and was IP66 certified against fine dust and water splashes from any direction. The components consisted of a battery, controllino MAXI microcontroller, 4G GSM modem, and RS485 in the TTL module. All devices were wired accordingly, and the wires leading to the sensors were soldered with connectors. The compartment was perforated as the outlet of the connector; in this case, the hole diameter was 16 mm. The water quality sensor was mounted on a PVC pipe to protect it from collisions or materials such as garbage or solid objects in the water. The pipe was then perforated so that water could pass through the sensor probe, and changes in water quality could be read by the sensor. The complete circuit is illustrated in Figure. 2.

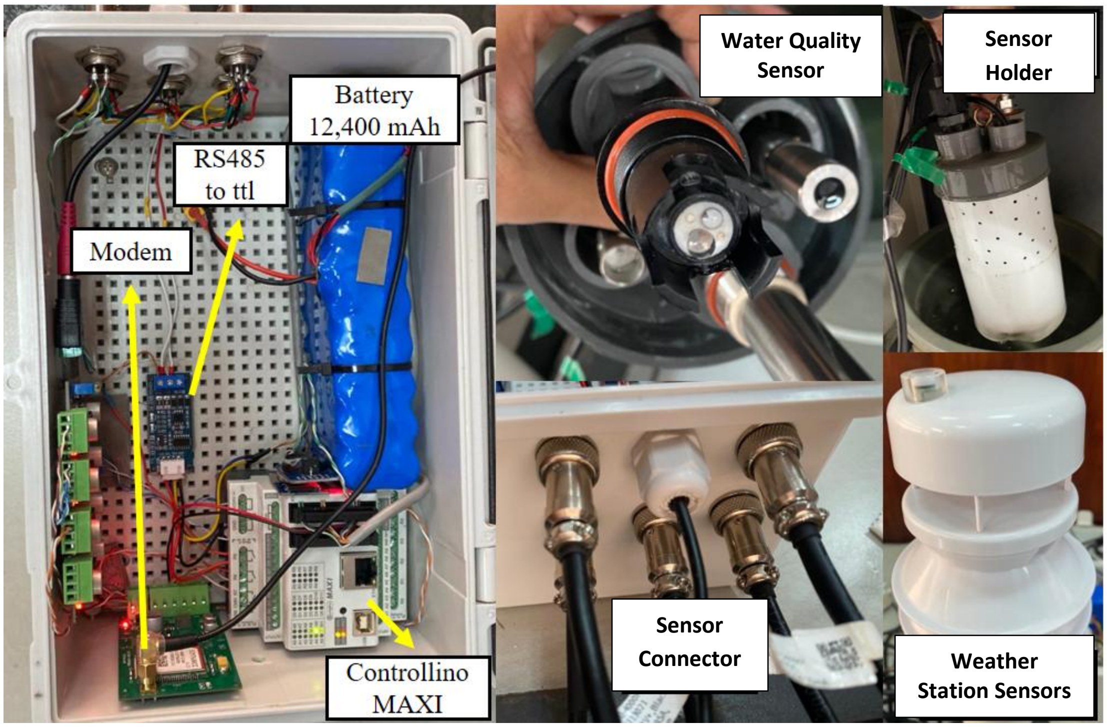

Figure 2. Monitoring System Hardware.

The sensor connector is detachable and can be swapped with any available socket. Switching sockets will not affect data transmission because the sensor circuit will follow the same path. This value is obtained by accessing the sensor ID and request code, and the sensor returns the value to the sensor.

3.2 Interface

The interface is filled with node locations with map interpretation as well as photos of the situation around the nodes. A time-series diagram is displayed to provide real-time parameter information. A clearer view is shown in Figure 3, where each node has a different home display according to the coordinates of its location. Users can easily recognize which node is being observed and where it is being located. The values sent by the sensors were neither changed nor rounded, nor were the error values removed or manipulated by the system. Error readings cause outlier values that can be analyzed, and outliers are caused by sensor reading errors resulting from incomplete data transmission packets from the sensor to the microcontroller or by the response time of each sensor.

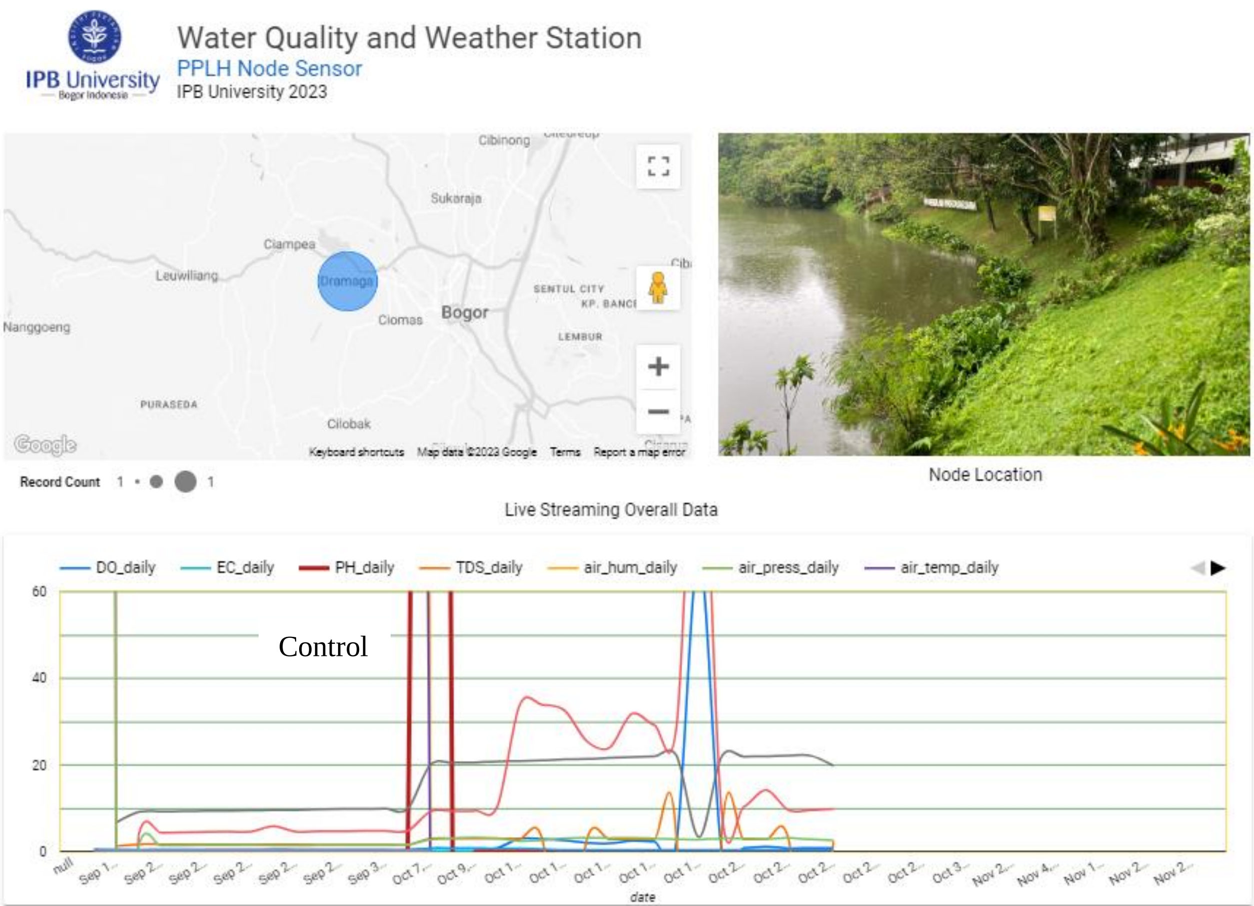

Figure 3. Main Page Interface.

Each parameter read by the sensor is available in a time-series graph, including percentile or quartile values. Quartile 1 (Q1) and quartile 3 (Q3) values serve as indicators of the upper and lower limits that divide normal and anomalous values, as shown in Figure 4. Observations with a duration of one day were averaged to represent the daily values of each parameter. Observation data with a duration of every 5 min are sent and stored in the form of tabular data that can be accessed by users. The intermediary medium for data transmission with MQTT increases the ease of data integration with any platform by utilizing servers for free (V et al. 2022). An example of the tabular data generated is shown in Figure 5, where the same information is copied on the data-logging card embedded in the system.

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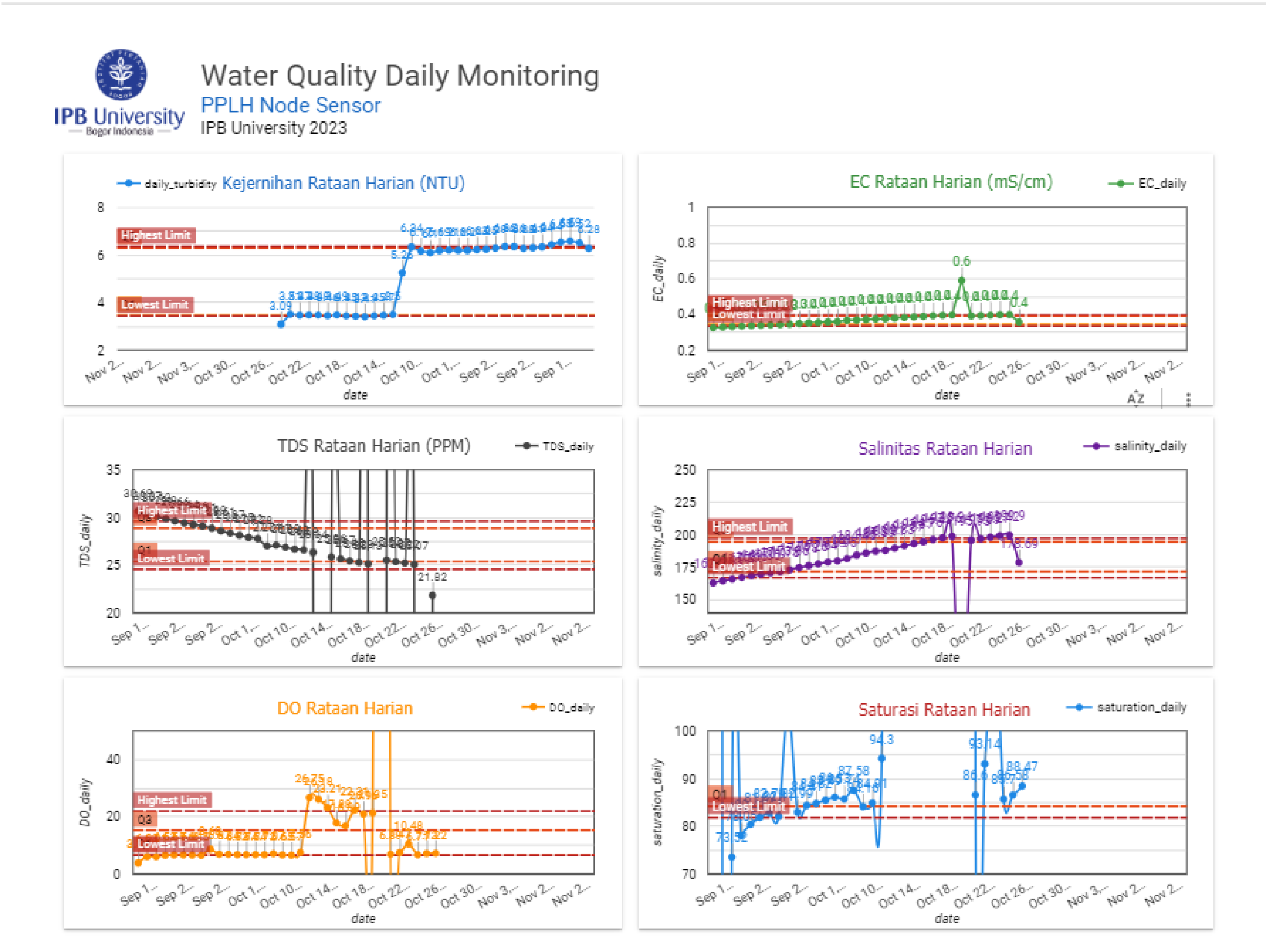

Figure 4. Measured Parameter Interface.

The format for sending data through the MQTT server includes the node name, sensor ID, rtc, and the sensor reading value. The rtc value used as a benchmark is the time at which the sensor receives the parameter-value request command. The time value is then sent as the payload data. Thus, the time displayed is the sensor reading time and not the time taken to receive data to the server.

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	A	B	C	D	E	F	G	H
59967	{"id":"PPLH001","ids":1	{"id":"PPLH001"	"ids":16	lue":2	"rtc'	16	29.20	2023/10/17
59968	{"id":"PPLH001","ids":1	{"id":"PPLH001"	"ids":15	e":211	"rtc'	15	211.53	2023/10/17
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59970	{"id":"PPLH001","ids":1	{"id":"PPLH001"	"ids":11	e":25.2	"rtc'	11	25.28	2023/10/17
59971	{"id":"PPLH001","ids":1	{"id":"PPLH001"	"ids":10	ue":0.3	"rtc'	10	0.40	2023/10/17
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59975	{"id":"PPLH001","ids":1	{"id":"PPLH001"	"ids":14	e":16.	"rtc'	14	16.38	2023/10/17
59976	{"id":"PPLH001","ids":1	{"id":"PPLH001"	"ids":16	lue":2	"rtc'	16	29.20	2023/10/17
59977	{"id":"PPLH001","ids":1	{"id":"PPLH001"	"ids":15	e":212	"rtc'	15	212.87	2023/10/17
59978	{"id":"PPLH001","ids":1	{"id":"PPLH001"	"ids":17	value":	"rtc'	17	0.00	2023/10/17
59979	{"id":"PPLH001","ids":1	{"id":"PPLH001"	"ids":10	ue":0.3	"rtc'	10	0.40	2023/10/17
59980	{"id":"PPLH001","ids":1	{"id":"PPLH001"	"ids":11	e":25.	"rtc'	11	25.10	2023/10/17
59981	{"id":"PPLH001","ids":1	{"id":"PPLH001"	"ids":12	ue":29	"rtc'	12	29.53	2023/10/17
59982	{"id":"PPLH001","ids":1	{"id":"PPLH001"	"ids":13	ue":19	"rtc'	13	199.20	2023/10/17
59983	{"id":"PPLH001","ids":1	{"id":"PPLH001"	"ids":18	e":3.38	"rtc'	18	3.39	2023/10/17

Figure 5. Tabular Time Series Data.

The format for sending data through the MQTT server includes the node name, sensor ID, rtc, and the sensor reading value. The rtc value used as a benchmark is the time at which the sensor receives the parameter-value request command. The time value is then sent as the payload data. Thus, the time displayed is the sensor reading time and not the time taken to receive data to the server.

4. Conclusion

After designing the tool, the following conclusions were obtained.

Water quality and weather sensor monitoring tools can be designed using the RS485 Modbus protocol and standard industrial microcontrollers, data transmission can be performed using MQTT server media, and the data can be accessed graphically and tabularly, data backup systems can be implemented using SD cards as the data-storage medium, and Additional information to help analyze data anomalies can be displayed on the interface graph.

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