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A Groundwater Quality Monitoring System Using IoT and GPS

Sally Lerian Edward[1]*, Riri Jonuarti[1], Mona Berlian Sari[1]

[1]*Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Negeri Padang, Padang, Indonesia*

*Corresponding author: sallylerianedward@gmail.com

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ABSTRACT

Conventional groundwater quality monitoring methods are often inefficient due to delays in data acquisition and limitations in spatial location tagging and automated data management. This study aims to develop a portable monitoring system based on NodeMCU ESP32 that is capable of measuring temperature, pH, TDS, and conductivity parameters in situ. The main innovation of this tool lies in the integration of a GPS module for mapping sample collection locations, automatic data storage to spreadsheets via an IoT platform, and a visual LED warning system calibrated according to the quality standards of PerMenKes No. 32 of 2017. Test results show that the system functions optimally with parameter accuracy levels reaching 95-99% and an error rate below 5% compared to standard measuring instruments. This system offers an effective solution for rapid, accurate, and digitally documented groundwater quality mapping.

1. INTRODUCTION

Water is one of the most important aspects of life that must be fulfilled in terms of both quantity and quality [1]. The most popular source of water for industrial and domestic uses is groundwater. According to data from the Center for Groundwater and Environmental Geology of the Geological Agency, Indonesia ranks ninth in the world with more than 90%[2]. The high dependence on groundwater and the increasing demand for water make groundwater quality a critical factor[3]. The availability of clean groundwater is becoming increasingly limited due to depletion caused by various human activities, such as pesticide use in the agricultural sector, domestic waste disposal, and pollution from urban areas that contaminate water sources [4]. Good groundwater must meet certain requirements to be used safely for human health, such as hygiene and sanitation standards outlined in Ministry of Health Regulation No. 32 of 2017. According to this regulation, good-quality water must meet certain limits such as a pH level between 6.5 and 8.5, Total Dissolved Solids (TDS) ranging from 100 mg/l, and water temperature equal to air temperature $\pm$ 30°C[5]. Therefore, continuous monitoring of these parameters is an essential diagnostic step for quickly assessing groundwater quality and is a necessity for sustainable water resource management.

To test groundwater quality, based on the Indonesian Nasional Standard (SNI 6989.58:2008) on water and wastewater, several tools are required to measure several field parameters such as a pH meter, conductivity meter and thermometer, as well as a Global Positioning System (GPS) to determine the coordinates and elevation of the location [6]. However, the effectiveness of testing these parameters is still carried out conventionally using several measuring instruments, and the records are not yet stored automatically. With the advancement of technology, various studies have focused on developing groundwater quality monitoring systems using modern technology. As demonstrated in study [7], a pH measurement system for well water has been successfully developed that is effective, cost-efficient, and easily accessible, with an alarm feature. However, the device only uses a single parameter and requires further development to incorporate simultaneous measurement of additional parameters.

Other studies showing the same trend, by researchers, by research [8] has developed a GPS – based system, but it still has high pH reading errors and does not include automatic timestamps. Meanwhile, the web based system by research [9] does not support spatial analysis due to the absence of a location module, and researchers [10], despite combining several parameters, does not have an IoT platform for automatic data storage for long-term trend analysis.

Based on the problems and limitations of previous studies, this research presents the results of developing an intelligent system for monitoring groundwater quality that is integrated, portable, and affordable. The novelty and superiority of this study lies in the combination of four important features in one system, namely multi-meter measurement (pH, TDS, electrical conductivity, and temperature), automatic data transmission to spreadsheet via IoT technology for historical database, precise coordinate location marking using GPS, and a system equipped with LED visual indicators calibrated according to threshold standards of PerMenKes No.32 of 2017 as a direct warning in the field. This combination successfully creates an effective monitoring solution by combining accurate technical data precision, instant on-site health standard validation certainty, and providing a conceptual historical database to support long-term sustainable groundwater quality management efforts.

2. METHOD

This research was conducted at the Electronics and Instrumentation Physics Laboratory, FMIPA, Universitas Negeri Padang and several groundwater sampling locations (dug wells) in Padang Utara District, Padang City, West Sumatra. This research is classified as engineering research, which involves the processes of design, development, testing, and evaluation that must meet certain criteria and requirements to become a product [11]. This monitoring system uses several electronic components, including a NodeMCU ESP32 microcontroller, a pH-4502C sensor module, a DS18B20 sensor, a TDS V.1 sensor module, a GT-U7 GPS module, an LCD, and an LED. The geometric arrangement of the block diagram of the groundwater quality monitoring system using IoT and GPS can be seen in Figure 1.

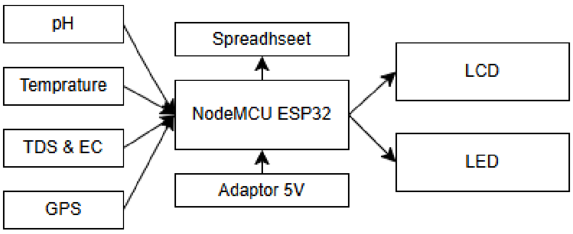


Figure 1. Block Diagram of Groundwater Quality Monitoring System Using IoT and GPS

Based on Figure 1**.,** The research block diagram has four main inputs, namely the pH-4502C sensor module to measure the acidity and alkalinity of groundwater, the DS18B20 sensor to measure groundwater temperature, the TDS V.1 sensor module to measure the number of dissolved solids and conductivity of groundwater, and the GT-U7 GPS module to record the geographical location of groundwater. The data from these four sensors will be collected and processed by NodeMCU ESP32 microcontroller. The measurement results will be displayed on two screens: directly at the location via an LCD screen and LED warning indicator if the values exceed the threshold, and simultaneously sent and stored in a spreadsheet via a Wi-Fi connection.

The hardware design is a combination of electronic circuits consisting of main components and supporting components in the system. The monitoring system is designed to be portable and uses ABS plastic material to protect the components from external environmental influences. The system is designed with dimensions of 180mm x 110 mm x 65 mm. The hardware designed for the monitoring system is illustrated in Figure 2.

Figure 2. Hardware Design for Groundwater Quality Monitoring System

Based on Figure 2., It can be seen that on the outside of the device, there are connection ports for pH, temperature, and TDS sensors. Meanwhile, on the top of the device, there are GPS and USB connection ports for power supply. The measurement results are displayed directly on the LCD screen, and red and green LEDs are used as visual indicators to warn if the parameters are within or outside the specified limits. Additionally, there is a switch to turn the device on or off when connected to a power source. Instructions are provided and the NodeMCU ESP32 microcontroller is programmed using the Arduino IDE software. The flowchart for the system operation is shown in Figure 3.

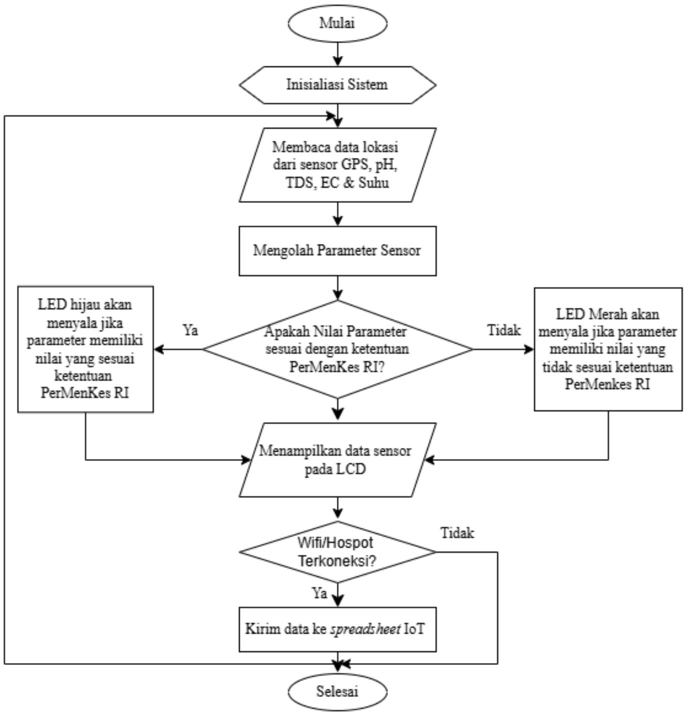


Figure 3. Flowchart of the Groundwater Quality Monitoring System

Figure 3., Shows the flowchart system. The system begins with sensor initialization, where all sensors are activated to prepare for measurement. Then, the sensors will take measurements of pH, TDS, temperature and location. After obtaining data from the four sensors, the data is processed by the Arduino IDE system, which converts it into values displayed on the LCD and provides information on whether the groundwater quality meets the standards set by the Indonesian Ministry of Health (PerMenKes RI) or not. The LED will provide visual warning information directly. Furthermore, if connected to Wi-Fi, the data will be sent to a spreadsheet via the IoT system. If not, the system will proceed directly to the next step.

Data collection techniques and performance testing of the monitoring system in the form of accuracy and precision values of the monitoring system. In this study, the first data collection is the characterization of each sensor, the second data is the accuracy of the measurement results, and the third data is the direct testing data at the groundwater location using the monitoring system that was created. After collecting the measurement data, data analysis is performed to draw conclusions from the measurement system.

3. RESULTS AND DISCUSSION

Based on the results of the design of a groundwater quality monitoring system using IoT and GPS, a device was developed to fulfil the research objectives. The research findings and data analysis include performance specification such as hardware development, electronic circuit forming the system, visual interface displays (LCD and LED), and spreadsheet-based data loggers. Design specifications include measurement results, specifically sensor characterization, accuracy of the developed monitoring system, and system testing data from the groundwater monitoring site. The research testing data presented is in the form of tables and graphs.

3.1 Hardware System

All components in the hardware are made according to the device's schematics and design. Images of the hardware and circuit of the monitoring system can be seen in Figure 4.

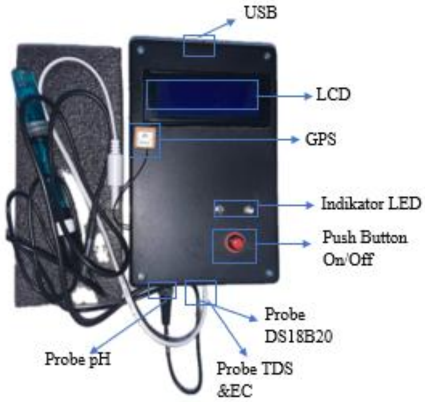


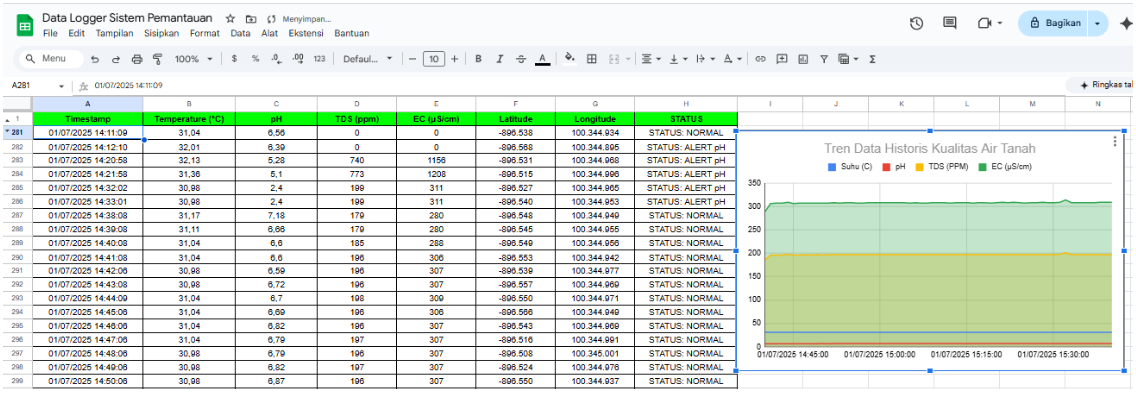
Figure 4. Hardware Image Groundwater Quality Monitoring System

Figure 4., Shows the hardware of the monitoring system after the design and assembly are complete. The entire system is placed in a compact and portable black plastic box designed to withstand physical damage and water splashes when used in the field. The container design also considers easy access to the LCD screen and LED lights. The electronic circuit forming the system is connected according to the pinout of the NodeMCU ESP32 microcontroller. The sensors function as input units that send data to the analog and digital pins of the ESP32. Meanwhile, the LCD and LED serves as output units that receive commands from the ESP32 to display quantitative information directly in the field. The integrated Wi-Fi module on the ESP32 is used for data communication to the IoT platform in the form of a spreadsheet.

3.2 Monitoring System Display

The section shows the output of the monitoring system in the form of an LCD screen as a direct visual interface, LED lights as warning status indicators, and a spreadsheet as IoT-based data storage. The display can be seen in Figure 5.

(a)



	Timestamp	Temperature (°C)	pH	TDS (ppm)	EC (µS/cm)	Latitude	Longitude	STATUS
281	01/07/2025 14:11:09	31,04	6,56	0	0	-896.538	100.344.934	STATUS: NORMAL
282	01/07/2025 14:12:10	32,01	6,39	0	0	-896.568	100.344.895	STATUS: ALERT pH
283	01/07/2025 14:20:58	32,13	5,28	740	1156	-896.531	100.344.968	STATUS: ALERT pH
284	01/07/2025 14:21:58	31,36	5,1	773	1208	-896.515	100.344.996	STATUS: ALERT pH
285	01/07/2025 14:32:02	30,98	2,4	199	311	-896.527	100.344.965	STATUS: ALERT pH
286	01/07/2025 14:33:01	30,98	2,4	199	311	-896.540	100.344.953	STATUS: ALERT pH
287	01/07/2025 14:38:08	31,17	7,18	179	280	-896.548	100.344.949	STATUS: NORMAL
288	01/07/2025 14:39:08	31,11	6,66	179	280	-896.545	100.344.955	STATUS: NORMAL
289	01/07/2025 14:40:08	31,04	6,6	185	288	-896.549	100.344.956	STATUS: NORMAL
290	01/07/2025 14:41:08	31,04	6,6	196	306	-896.553	100.344.942	STATUS: NORMAL
291	01/07/2025 14:42:06	30,98	6,59	196	307	-896.539	100.344.977	STATUS: NORMAL
292	01/07/2025 14:43:08	30,98	6,72	196	307	-896.557	100.344.969	STATUS: NORMAL
293	01/07/2025 14:44:09	31,04	6,7	198	309	-896.550	100.344.971	STATUS: NORMAL
294	01/07/2025 14:45:06	31,04	6,69	196	306	-896.566	100.344.949	STATUS: NORMAL
295	01/07/2025 14:46:06	31,04	6,82	196	307	-896.543	100.344.969	STATUS: NORMAL
296	01/07/2025 14:47:06	31,04	6,79	197	307	-896.516	100.344.991	STATUS: NORMAL
297	01/07/2025 14:48:06	30,98	6,79	196	307	-896.508	100.345.001	STATUS: NORMAL
298	01/07/2025 14:49:06	30,98	6,82	197	307	-896.524	100.344.976	STATUS: NORMAL
299	01/07/2025 14:50:06	30,98	6,87	196	307	-896.550	100.344.937	STATUS: NORMAL

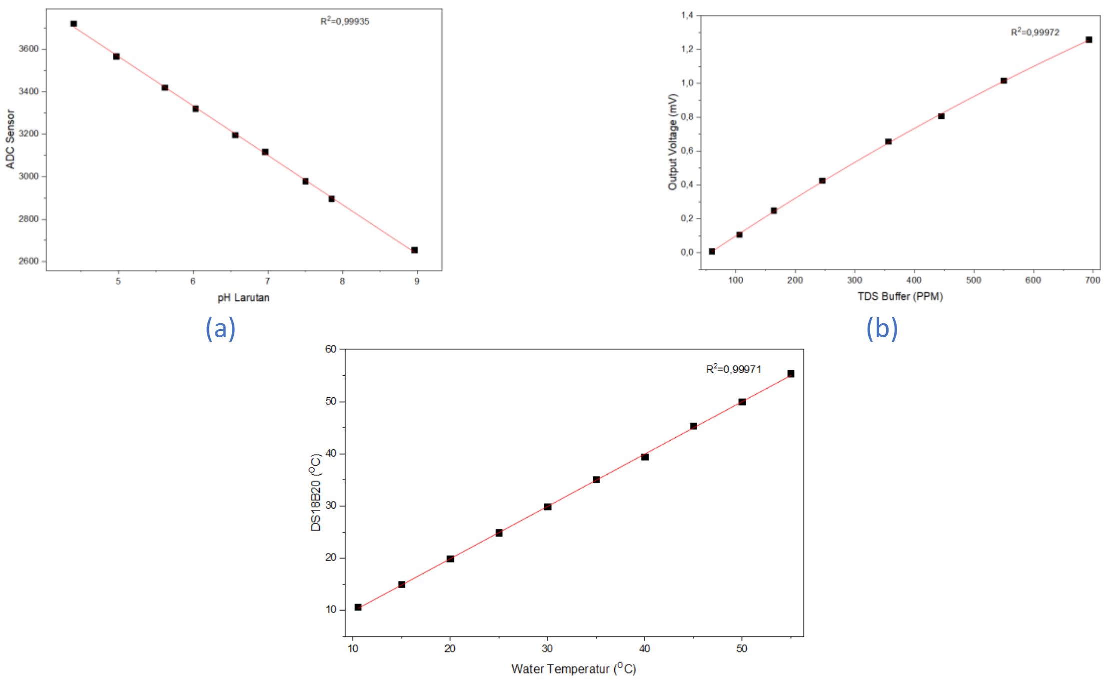
(b)

Figure 5. Groundwater Quality Monitoring System Display

Figure 5(a)., Shows a visual representation of the monitoring system in the form of an LCD screen that successfully displays quantitative data obtained directly in the field. This screen will show precise values for temperature, pH, TDS, EC, and provide information on groundwater quality status, as well as visual warnings in the form of LEDs if the values are within or outside the standard limits set by PerMenKes RI No.32 of 2017. Meanwhile, Figure 5(b)., Illustrates the process of data collection and storage, which is automatically performed on a data logger using IoT technology. Data from this system is stored in a structured spreadsheet format that can be processed and analysed in the event of anomalies in groundwater quality.

3.3 Measurement Data

The first result of this study is the characterization of each sensor. Sensor characterization aims to determine the sensor's capability against standard measuring instruments to see the linearities [12]. In this study, sensor characterization was carried out to determine the performance of a detail so that it can provide accurate, reliable and appropriate information. The sensor characteristics are shown in Figure 6. and Table 1.



(a) (b)

(c)

Figure 6. (a). Characterization of pH sensors, (b). Characterization of TDS sensors, and (c). Characterization of DS18B20 sensors

Figure 6(a). Shows the characterization of the pH sensor, which was performed by determining the relationship between the actual pH values of acidic, neutral and basic solutions compared to the sensor output values ADC, resulting in an R^2 of 0,99935, indicating the sensitivity of the sensor. The higher the pH value, the lower the ADC value is obtained. Figure 6(b)., shows the characterization of the TDS sensor, which yielded an R^2 value of 0,99972, where the higher the PPM value provided, the higher the output voltage. The electrical conductivity value was obtained by dividing the PPM value read by the sensor by the soil water conductivity coefficient, as shown in equation (1) [13].

$$EC = \frac{TDS}{0{,}64} \tag{1}$$

Figure 6 (c)., Shows the characterization of the temperature sensor, which obtained an R^2 value of 0,99971, where the data obtained have a direct relationship. The characterization table for the GPS sensor is shown in Table 1.

Table 1. Characterization of the GT-U7 GPS Sensor

Environmental Conditions	Number of Satelit	Signal Quality
Open Space	10-11	Fast and stable signal
Semi-open are (trees)	8-9	Good and fairly stable
Urban Area (High-Density)	5-7	Less stable
Indoor (Near Window)	3-4	Quite a long time

Table 1., Shows the characterization of the GPS sensor, which was done by comparing location points using Google Earth with the output results in the form of latitude and longitude coordinates from the sensor. The data obtained prove that environmental quality is a determining factor in the satellite signal captured by the sensor.

The second result from the research data is the testing of the monitoring system that was created compared to a calibrated standard measuring device, where good accuracy is achieved when the sensor obtains values close to the actual values [14]. Laboratory-scale testing was carried out as an initial validation stage to ensure the level of precision and accuracy of the sensor before the system was implemented in more complex field conditions. This testing involved 10 data collection sessions using a variety of water samples designed to represent various water sample characteristics, pH buffer variations, TDS levels, and temperatures under various conditions. In actual data of the monitoring system can be seen in Table 2.

Table 2. Testing Data Between Monitoring System and Standard Tools

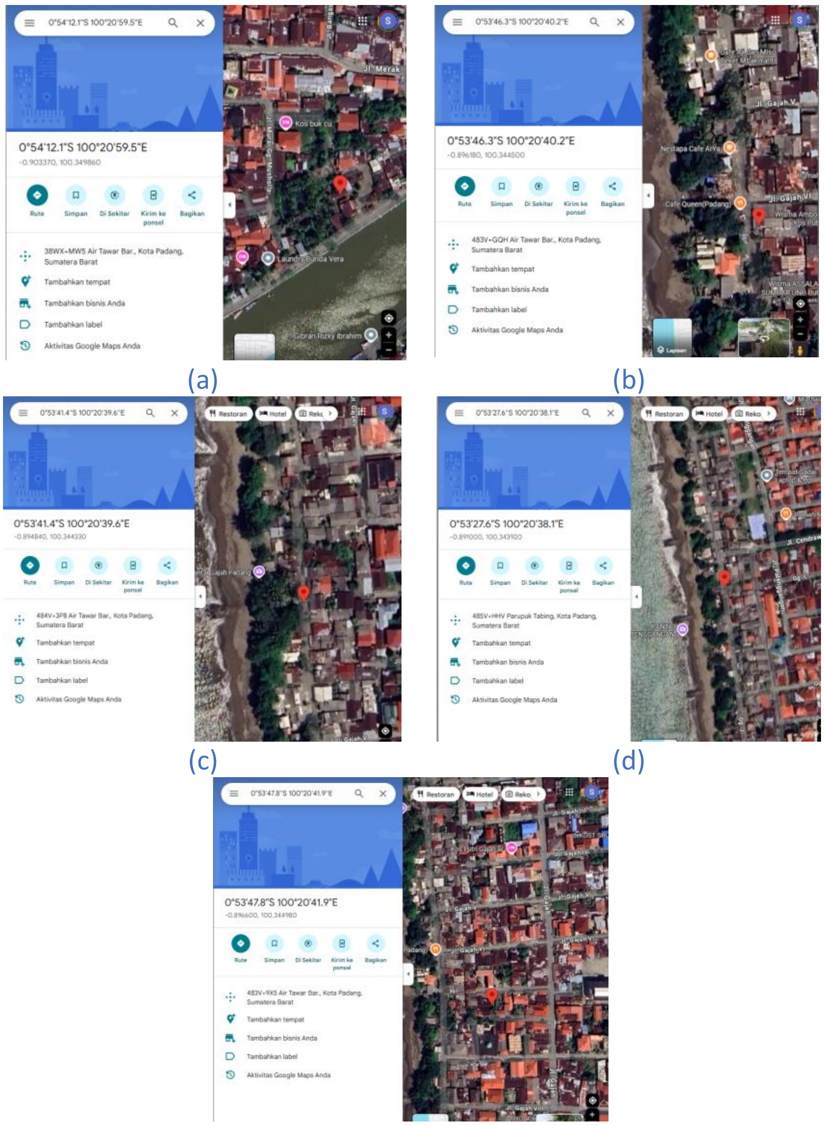
Measure-ment	pH System	pH SNI	TDS System (PPM)	TDS Meter (PPM)	EC System ($\mu S/cm$)	EC Theoretical ($\mu S/cm$)	Temp System (°C)	Termometer (°C)
1	4,53	4,76	64	63,2	100	99	58,2	58
2	5,36	5,51	183	178	286	278	52,4	52,5
3	5,58	5,78	180	185	281	289	47,9	48
4	6,37	6,49	258	257	403	402	42,4	42
5	6,4	6,51	258	272	403	425	35,7	35,5
6	6,79	6,89	266	281	416	440	29,8	30,1
7	6,74	6,95	441	439	689	686	22,9	22,7
8	6,93	7,13	543	538	848	841	19,8	20
9	6,92	7,06	540	543	844	848	13,8	14
10	7,11	7,16	594	574	928	899	9,3	9

Note:
System & Theoretical $EC = {}^{TDS}/_{0{,}64}$ [13].

Table 3. Accuracy of Parameter Precision Groundwater Quality Monitoring System

Parameter	Accuracy
pH	97,32%
TDS (PPM)	97,78%
EC ($\mu S/cm$)	97,82%
Temp (℃)	98,99%

Based on Table 3., The results of the monitoring system testing showed that the average accuracy of the system ranged from 97% to 99% for all measured parameters. This proves that the values obtained by the monitoring system are almost the same as those obtained by the standard instrument. The test results obtained show that the accuracy of all parameters is over 70%, meaning the monitoring system is functioning properly and providing accurate readings [15]. Third, the monitoring system testing at the groundwater location is shown in Figure 7. And Table 4.



(a) (b) (c) (d) (e)

Figure 7. Groundwater Location

Table 4. Field Testing Groundwater Quality Parameter Monitoring System

Groundwater Location	**Parameters**				**Status Groundwater**	**LED Condition**
	pH	**TDS (PPM)**	**EC ($\mu S/cm$)**	**Suhu (℃)**		
Latitude: -0,90337 Longitude: 100,34986	6,84	291	455	29,5	Normal	Green
Latitude: -0,89618 Longitude: 100,34450	7,30	351	548	28,5	Normal	Green
Latitude: -0,89484 Longitude: 100,34433	7,53	119	186	28,0	Normal	Green
Latitude: -0,89100 Longitude: 100,34392	7,19	619	967	29,6	Normal	Green
Latitude: -0,89660 Longitude: 100,34498	6,78	209	327	30,1	Normal	Green

Based on Figure 7. And Table 4., it shows that the groundwater quality monitoring system is running well and according to plan. The development of a groundwater quality monitoring system using IoT and GPS has both advantages and disadvantages. The advantage of this monitoring system is that it combines multi-parameter measurements such as pH, TDS, EC, and temperature with groundwater location tracking. This monitoring system utilizes an IoT platform to transform devices from measuring instruments into smart data systems capable of creating a historical database that is automatically stored, centralized, and easily accessible. Additionally, the system is designed to bridge quantitative data and provide instant alerts to users through visual indicators using LEDs, in accordance with Indonesian Ministry of Health Regulation No: 32 of 2017. So that users can determine the quality of the groundwater through the monitoring system developed. Although the system functions well, interference between sensors was found, particularly the influence of the pH sensor on the accuracy of TDS readings, causing a shift in values. This is thought to be due electrical noise or current flow in the same liquid when both sensors are active simultaneously. As a short-term solution, the physical distance between sensors should be adjusted to prevent them from being too close. For further research, it is recommended to use an analog signal isolator module or switching technique in microcontroller coding to eliminate electrical interference. In addition, the development of an offline data storage system is needed as a backup when internet access is limited, thereby increasing the reliability of the system in remote locations.

4. CONCLUSION

Based on the test result, data analysis, and discussion of the development of a groundwater quality monitoring system using IoT and GPS, several conclusions can be drawn, namely: the performance specifications of a groundwater quality monitoring system using IoT and GPS consist of four parts, including the mechanical construction of the monitoring system, which comprises a black box and the assembly of electronic circuits such as the NodeMCU ESP32 microcontroller, pH 4205C module, DS18B20 sensor, TDS V.1 module, GPS GT-U7, LCD, LED indicator, switch, and sensor probe. The visual display, consisting of an LCD and LED, ensures that displayed data and visual indicators function properly according to the conditions. This monitoring system has also proven reliable in transmitting data to a storage link in the form of a spreadsheet, enabling users to easily store and analyze the data further. The design specifications of a groundwater quality monitoring system using IoT and GPS consist of three parts, namely sensor characterization, which is carried out to ensure that sensor readings are in accordance with standard instruments and theoretical calculations, and the accuracy of all sensor readings ranges from 95% to 99%, so that this monitoring system has great potential for widespread use.

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DECLARATIONS

Authorship contribution

Sally Lerian Edward: Conceptualization, methodology, formal analysis, software and writing -original draft.
Riri Jonuarti And Mona Berlian Sari: Methodology, Validation, data curation and writing –review and editing.

Competing Interest

The authors **declare** no conflict of interest in this study.

Funding statement

This work has not been funded by any person or organization.

Ethical Clearance

There are no human subjects in this manuscript, and informed consent is not applicable.

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