Design and development of coastal marine water quality monitoring based on IoT in achieving implementation of SDGs

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ABSTRACT

Indonesia, an archipelagic nation with about 70% ocean territory, relies on oceanographic data for efficient marine environment monitoring and natural resource sustainability. Current data collection is limited by tools measuring only single parameters and lengthy data collection times. This study proposes a marine coastal water quality monitoring tool based on the internet of things (IoT), capable of simultaneously measuring temperature, electrical conductivity, pH, and dissolved oxygen. Utilizing an Atmega328 and a battery lasting up to 119 hours, this system offers a cost-effective solution for real-time oceanographic data collection. Employing the ADDIE methodology, the results demonstrate high measurement accuracy compared to traditional methods, with accuracy of 90.5% for temperature, 93.50% for electrical conductivity, 93.67% for pH, and 96.82% for dissolved oxygen. The development of this tool aims to reduce costs and labor in capturing oceanographic data integrated with IoT, facilitate access and monitoring of water data, and make a significant contribution to achieving SDGs targets. The main focus on the goals of addressing climate change and life underwater, especially in the aspects of water resources management and protection of marine ecosystems in Indonesian.

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1. INTRODUCTION

Indonesian is the country with the largest archipelago in the world, covering approximately 640 million km^2 of sea area, strategically located betwwen the Indian Ocean and the Pacific Ocean. These geographical characteristics not only make Indonesia rich in marine resources but also present significant challenges in monitoring and managing oceanographic conditions [1], [2]. There is an urgent need for oceanographic monitoring that is both effective and efficient, in response to the fast and varied environmental changes [3]. Nevertheless, existing oceanographic monitoring and data gathering instruments are often constrained in their functionality, generally capable of tracking just a single environmental parameter at any one time [4]. The constraint impedes the through comprehension of the water circumstances in Indonesian. Furthermore, devices with the ability to measure many parameters are sometimes excessively costly and need significant expenditures in terms of finansial resources, time, and personnel for doing direct field measurements [5], [6].

Although prior research has examined the necessity of thorough and ongoing oceanic monitoring, there remains a notable deficiency in the accessibility of affordable, instantaneous devices capable of measuring numerous parameters concurrently. Melinda and Nurhadiyah [7] conducted an analysis of the quality of saltwater in Gili Air, North Lombok, with a particular focus on highlighting the need of implementing extensive monitoring systems. In their study, Briciu-Burghina *et al.* [8] conducted a comprehensive analysis of the use of sensors in coastal and ocean monitoring. They observed the progress made in existing technologies as well as the constraints they still face. However, there are still unanswered concerns about the cost, precision, and availability of real-time oceanographic data gathering systems, despite the efforts made to addrees them [9].

To overcome these difficulties, this work presents a new coastal marine water quality monitoring system based on the internet of things (IoT) [10]. This device seeks to concurrently monitor many parameters, including temperature, electircal conductivity, pH, and dissolved oxygen, using Atmega328 microprocessor. The suggested system is meant to be cost-effective and capable of delivering real-time data, hence boosting accessibility and efficiency in monitoring marine water quality. This research contributes by inventing a multi parameter monitoring system that incorporates several sensors to measure critical oceanographic parameters concurrently. Utilizing IoT technology, the system provides real time monitoring capabilities at a reduced cost, thereby supporting the achievement of sustainable development goals (SDGs), specifically SDGs point 13 (climate action) and SDGs point 14 (life below water), by facilitating better management and protection of marine ecosystems. The succeeding parts of this paper discuss the approach, results, and importance of the proposed system. The methodology section discusses the ADDIE framework applied in the system development. The results and discussion section assesses the system performance, comparing it with conventional approaches to highlight gains in accuracy and efficiency. Finally, the conclusion analyzes the important results and their significance for future research and practical applications.

2. METHOD

2.1. Research design

The research undertaken in this study comes under the area of applied design techniques, especially applying the ADDIE method, which is highly renowned for its methodical approach in producing useful technical solutions [11], [12]. This research is meant to address the demand for enhanced water quality monitoring system by following an organized procedure. This methodical path, as represented in Figure 1, enables the construction of a reliable and effective water quality monitoring system.

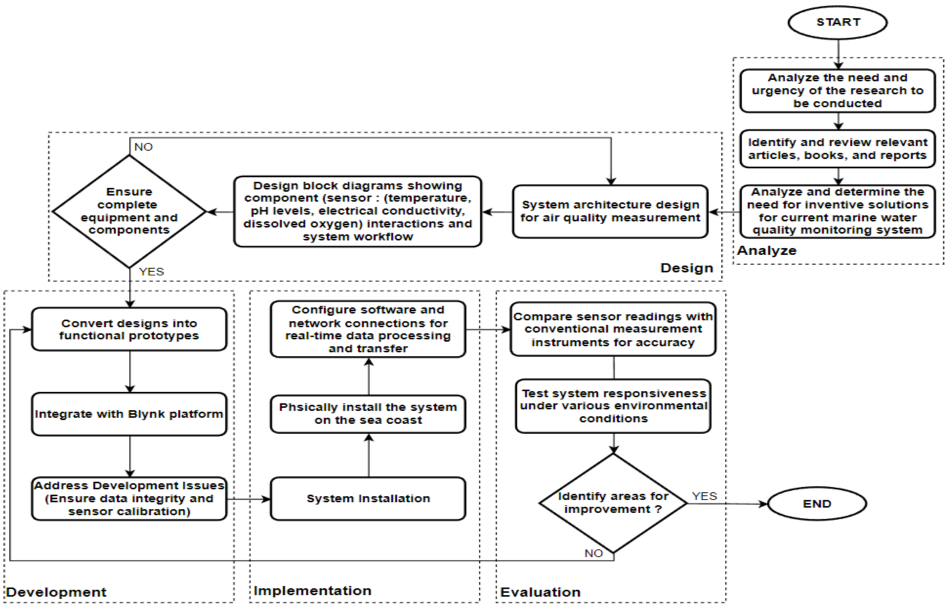

Figure 1. Research design

Based on the Figure 1, In the initial step, a detailed literature study was undertaken, focusing on the limitations of current marine water quality monitoring systems, specifically in accuracy and real-time data accessibility [13], [14]. The design stage followed, when a cost-effective and user-friendly system architecture was built, combining sensors for temperature, pH, electrical conductivity, and dissolved oxygen levels. The design process also involves developing block diagrams to demonstrate component relationships and system workflow [15]. During the development stage, concepts were transformed into functioning prototypes utilizing an Atmega328 microcontroller and GSM module, connected with the Blynk platform for real-time data processing and transfer. Key issues, such as maintaining data integrity and sensor calibration, were overcome. The equipment was then physically erected on the sea coast, with software configuration and network connections permitting seamless data transmission. Finally, system performance was tested by comparing sensor values with conventional equipment and assessing response under various environmental circumstances. This evaluation was crucial in identifying areas for improvement and verifying the system's preparedness for wide deployment [16].

2.2. Architecture and block diagram system

The device produced in this research takes a complete strategy encompassing sensor usage protocols, inclusion of sensor components, implementation of algorithms, and measurement and analysis methodologies for troubleshooting. The general architecture and block diagram of the system are represented in Figure 2 and Figure 3. This integration offers a comprehensive and efficient design, permitting real-time monitoring and data recording for accurate environmental evaluation [17].

The system is based around an ATmega328 Microcontroller coupled with a GSM modem to manage data connection. This microcontroller acts as the central processing unit that connects and controls the various sensors used in the study. These sensors comprise a pH sensor to monitor the acidity level of the environment, a DS18B20 temperature sensor to measure temperature, a dissolved oxygen sensor to evaluate the quantity of oxygen dissolved in water, and a conductivity sensor to assess the conductivity level of water. To guarantee precise time recording, the system is equipped with an real-time clock (RTC) module. Data acquired by these sensors is kept on an SD card module and then converted to an Excel file for further study. In addition, the system leverages an API to simplify data transmission to a web server, giving remote access to data. The Blynk cloud offers data visualization and monitoring, giving real-time access to data via devices such as smartphones or personal computers. This flexibility enables users to monitor environmental conditions from anywhere at any time.

The system's architecture may be further comprehended by its block diagram from the Figure 3, which is separated into three primary parts: input, process, and output. Each section of the block diagram has particular and distinct purposes. The input section comprises the sensors that gather environmental data. The process element involves the microcontroller and GSM module, which process and send the data. Finally, the output section comprises of data storage, data export to Excel, and remote monitoring via the web server and Blynk platform [18], [19]. The arrangement and integration of these aspects enable the system to offer real-time monitoring and data recording, crucial for efficient and accurate environmental evaluation. Each component and process has been carefully developed and chosen to guarantee the reliability and repeatability of these studies.

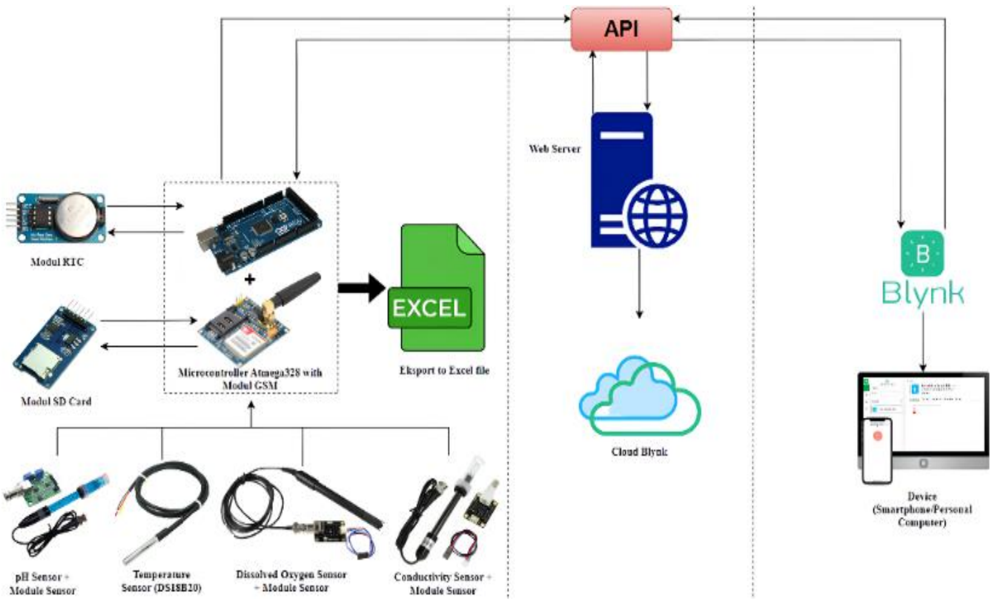

Figure 2. Architecture system

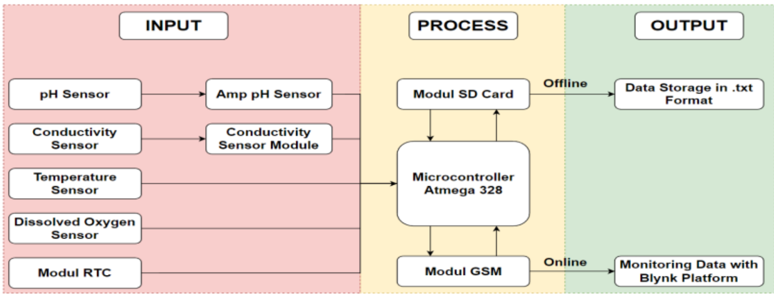

Figure 3. Block diagram system

2.3. Flowchart system

In the Figure 4, it shows how the designed marine coastal water quality monitoring system works. The monitoring tool is turned on and left to float in the water, the sensors used will immediately read the measured water quality parameters. After that, the microcontroller receives data and processes the data obtained from the sensor output to be sent to the storage system or displayed via the interface [20]. The working process of the tool created will work continuously before the battery power on the tool runs out and the battery power can be monitored online and remotely via the Blynk platform interface as an indication that the battery condition is almost empty so that it can be refilled as soon as possible [21].

Flowchart questions for “works?”, refers to the critical validation stage where the system determines whether the sensor values meet the applied requirements. This phase is critical to ensure data integrity before visualization. If the data does not meet the required standards, re-calibration steps or algorithm modifications are required to improve sensor performance. After validation, the correct sensor values are sent and displayed via the Blynk platform. Users can access water quality data on the sea coast which is presented in an easy to understand and practical way.

Figure 4. Flowchart system

2.4. Sensor characterization

Many equipment or tools require basic electrical principles in their operation, and practically all systems for collecting, transferring, and analyzing data depend on electronic gadgets. Monitoring saltwater quality entails simultaneous measurements of temperature, salinity, pH, and dissolved oxygen, which require sensors and transducers put at the observation location [22]. While datasheets give basic sensor parameters, field testing is crucial to evaluate performance under real-world settings, which often differ from lab surroundings. Field characterization guarantees data accuracy and dependability for coastal marine water quality monitoring, vital for environmental policymaking.

In this research, the characterisation of four sensors was conducted: the electrical conductivity sensor, pH level sensor, dissolved oxygen sensor, and DS18B20 temperature sensor. For salinity measurement, the conductivity sensor calculates the fluid's electrical conductivity. The output voltage is determined using in the (1).

$$V_o = \frac{value\ sensor}{4096}\ x\ 3{,}4\ volt \tag{1}$$

2.4.1. Electrical conductivity sensor

Output value from the conductivity sensor in units µS/cm, then the conversion process is carried out to the quantity required in this research, namely parts per million (ppm). At the stage of the conversion process to ppm, there are several types of scales that are related to the type of water content identified [23]. In this research, specifically to monitor the quality of coastal waters, we used values for the type of water content containing sodium chloride (NaCl). The converted ppm level is ppm-500. The following is the equation for converting the measured conductivityµS/cm to ppm 500 scale [24]. The following are the results of the calculations obtained by the output value of conductivity and ppm scale 500 against the output voltage (volt).

$$ppm\ scale\ 500 = \frac{1}{2} * \left(value\ DO\ sensor\ \left({}^{\mu S}/_{cm}\right)\right) \tag{2}$$

Based on the Figure 5, it shows a graph to get the conductivity value and the conversion results into a ppm scale 500 units for the output voltage. The (3) which relates the conductivity value and an (4) which relates the 500 ppm scale value to the output voltage.

$$\sigma\left({}^{\mu S}/_{cm}\right) = \begin{cases} \frac{V_O - 0.003}{0.009}, 0.109 \le V_o \le 1.186 \\ e^{\left(\frac{V_O - 4.063}{1.093}\right)}, 1.186 \le V_o \le 3.5 \end{cases} \tag{3}$$

$$ppm\ scale\ 500 = \begin{cases} \frac{1}{2}\left(\frac{V_O - 0.003}{0.009}\right), 0.109 \le V_o \le 1.186 \\ \frac{1}{2}\left(e^{\left(\frac{V_O - 4.063}{1.093}\right)}\right), 1.186 \le V_o \le 3.5 \end{cases} \tag{4}$$

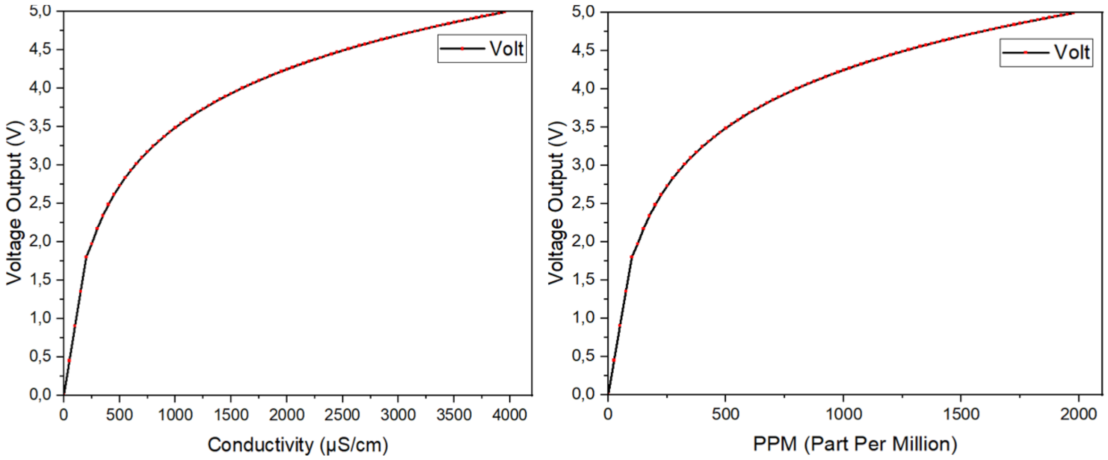

Figure 5. Graph of conductivity and PPM against output voltage

2.4.2. pH sensor

The pH sensor consists of a sensor and reference electrode that reads the potential difference between the two. This sensor is a tool used to measure the acidity or alkalinity level of a substance using a quantitative scale ranging from 0 to 14, which is defined as the negative algorithm of the concentration of hydrogen ions [H+] [25]. The pH sensor is calibrated using at least two pH buffer solutions to cover the sample values. This calibration is carried out based on the expected pH value of the pH buffer solution at various temperatures based on the ISO 10523 standard:

$$E_{pH} = E_{pH0} - 2.3\frac{RT}{nF}log([H^{+}]) \quad (5)$$

$$E_{pH} = E_{pH0} - 0.23\gamma_{PH}pH \quad (6)$$

As shown in Table 1, the output voltage of the pH sensor varies with temperature. These values demonstrate how the compensation factor (γ_{PH}), which is 54.20 mV/pH when the temperature is 0 °C, 25 °C, 50 °C, and 100 °C. The Op-Amp amplifier circuit is used to increase the output voltage of the pH probe. An analog pH sensor/meter used with an Atmega328 microcontroller is used to obtain pH values to assess water quality. This analog pH sensor consists of a sensor and reference electrode in a potentiometer arrangement [26]. This setup allows measurement of the potential difference between the sensor and reference electrodes, thereby facilitating accurate pH readings.

Table 1. Results of pH levels against output voltage in various temperature conditions

Temperature (ºC)	Buffer 4.01 pH		Buffer 7 pH		Buffer 10.01 pH	
	pH	V_o	pH	V_o	pH	V_o
0	4.01	217.342	7.12	385.904	10.32	559.344
5	4.01	217.342	7.09	384.278	10.25	555.55
10	4.00	216.8	7.06	382.652	10.18	551.756
15	4.00	216.8	7.04	381.568	10.12	548.504
…	...	...	...	...	...	...
40	4.03	218.426	6.97	337.774	9.89	536.038
45	4.04	21.8.968	6.97	337.774	9.86	534.412
50	4.06	220.052	6.97	337.774	9.83	532.786
55	4.08	221.136	6.97	337.774	9.81	531.702

2.4.3. Dissolved oxygen sensor

The amount of oxygen (O_2) dissolved per unit volume (mg/L) is called dissolved oxygen (DO). The partial pressure of oxygen in the atmosphere is proportional to the amount of oxygen dissolved in the water. Most aquatic life, such as fish, invertebrates, bacteria and plants, use oxygen for respiration, just as land organisms need DO. Other factors such as aquatic temperature, salinity, barometric pressure, and flow can affect the readings from a DO sensor [27].

Anode oxidation reaction: $2Zn \rightarrow 2Zn^{2+} + 4^{e-}$
Cathode reduction reaction: $O_2 + 4^{e-} + 2H_2O \rightarrow 4OH^{-}$
$4OH^{-} + 2Zn^{2+} \rightarrow 2Zn(OH)_2$
Total reaction: $2Zn + O_2 + H_2O \rightarrow 2Zn(OH)_2$

The current generated is proportional to the partial pressure of oxygen, which is determined using the (7).

$$i_{DO} = \frac{4F\mu_{MB}(T)A_{MB}p_{O_2}}{d_{MB}} \quad (7)$$

The membrane's permeability, area, and thickness are represented by $\mu_{MB}(T)$, A_{MB}, and d_{MB}. Respectively, while p_{O_2} represents the partial pressure of oxygen [28]. The sensor's performance changes with temperature, as shown in Table 2. For instance, at 0 °C, the output voltage for 1 mg/L DO is 1.019 V, whereas at 40 °C, it climbs to 1.169 V. This variance emphasizes the influence of temperature on the sensor's readings, emphasizing the necessity for calibration to maintain reliable observations across diverse situations.

Table 2. Results of dissolved oxygen value against output voltage in various temperature conditions

DO (mg/L)	Temperature to output voltage (°C to volt)								
	0	5	10	15	20	25	30	35	40
0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
0.5	1.01	1.015	1.020	1.025	1.033	1.041	1.048	1.067	1.085
1	1.019	1.030	1.041	1.050	1.067	1.081	1.097	1.134	1.169
1.5	1.028	1.046	1.061	1.075	1.1	1.122	1.145	1.200	1.254
2	1.038	1.061	1.081	1.1	1.133	1.162	1.194	1.267	1.338
...	…	…	…	…	…	…	…	…	…
8	1.151	1.244	1.325	1.4	1.533	1.650	1.774	2.068	2.354
8.5	1.161	1.259	1.345	1.425	1.567	1.691	1.823	2.135	2.438
9	1.170	1.274	1.366	1.450	1.6	1.731	1.871	2.202	2.523
9.5	1.180	1.290	1.386	1.475	1.633	1.772	1.920	2.268	2.607
10	1.189	1.305	1.406	1.5	1.667	1.812	1.968	2.335	2.692

2.4.4. DS18B20 sensor

The DS18B20 sensor is used as a sensor to measure temperature in coastal waters. We try to analyze and evaluate this sensor to find out its characteristics by measuring the type of water it has reactive index different, this aims to measure the extent of consistency of the sensors used in various existing conditions [29], [30]. The temperature range tested runs from 20 °C to 90 °C over three distinct reactivity indices (1.4732, 1.4782, and 1.4786). The output voltage corresponding to these circumstances is reported in Table 3. For instance, at 20 °C, the output voltage is 0.42 mV for all reactive indices. At higher temperatures, such as 90 °C, the output voltage fluctuates slightly: 1.88 mV for RI = 1.4732, 1.89 mV for RI = 1.4782, and 1.890 mV for RI = 1.4786. This variation displays the sensor's reaction to diverse water conditions, offering insight into its consistency and accuracy across multiple reactive indices.

$$V_o(mV) = (0.021 * Temperature) + 0.1\mu \quad (8)$$

Table 3. Results of DS18B20 value against output voltage in various reactive index conditions

Temperature (°C)	Reactive index (RI) to output voltage		
	RI = 1.4732	RI = 1.4782	RI = 1.4786
20	0.42	0.42	0.420
25	0.53	0.53	0.525
30	0.63	0.63	0.630
35	0.73	0.74	0.735
…	…	…	…
75	1.57	1.57	1.575
80	1.67	1.68	1.680
85	1.78	1.78	1.785
90	1.88	1.89	1.890

2.5. Sensor performance metrics

In this research, we performed a complete evaluation and analysis of the sensors incorporated into the coastal marine water quality monitoring system. The functioning of these sensors is vital to guaranteeing accurate and reliable data gathering, which is required for successful environmental monitoring. To completely analyze the sensor performance, we utilized numerous essential parameters. These metrics give a complete insight of how effectively the sensors work under different settings and how their findings relate to established reference values. The following metrics were used to assess the sensor performance.

$$Error\ (\%) = \left(\frac{Measured\ Value - Reference\ Value}{Reference\ Value}\right) x\ 100\% \quad (9)$$

$$Standard\ Error = \frac{\sigma}{\sqrt{n}} \quad (10)$$

$$Accuracy\ (\%) = \left(1 - \left|\frac{Measured\ Value - Reference\ Value}{Reference\ Value}\right|\right) x\ 100\% \quad (11)$$

$$Standard\ Deviation\ (\sigma) = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \mu)^2} \quad (12)$$

3. RESULTS AND DISCUSSION

This research established an IoT system for monitoring coastal marine water quality, delivering real-time data on temperature, electrical conductivity, pH, and dissolved oxygen. The system was developed for efficiency, accuracy, and cost-effectiveness, playing a critical role in maintaining marine ecosystems and promoting SDG 13 (climate action) and SDG 14 (life below water). Key results reveal that the system offers great accuracy and dependability, exceeding conventional methods in real-time monitoring. Battery life testing showed its endurance across varied conditions, and data observations supported its usefulness in detecting water quality changes. These findings underscore the system’s potential for expanded usage in marine conservation programs.

3.1. Hardware system design

The maritime coastal water quality monitoring system is contained inside a 4-inch PVC tube that is 50 mm long, specifically built to hold electrical components and sensors. In order to provide buoyancy and stability against wave motions, a styrofoam float with a diameter of 280 mm and a height of 200 mm was included into the system to guarantee it remains afloat on the sea surface. This design option permits the system to stay functioning under diverse sea conditions.

The system has three basic pieces as depicted in Figure 6. Part A contains the SIM800L GSM module at the top, increasing signal reception. Part B, the center component, houses the battery and microprocessor, ensuring central control and power management. Part C, the bottom piece, holds the sensors and is in close contact with water, allowing for accurate and quick data collecting.

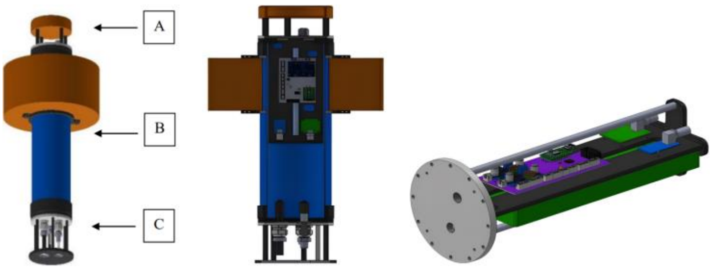

Figure 6. Design of monitoring seawater quality

This structure provides effective organization and protection of components. Modules that need rapid access are positioned at the top to keep them secure from water. External signal modules, including switches, micro SD cards, GPS, and GSM modules, are also positioned for best performance. This architecture promotes simple maintenance and updates. The system’s core, situated in the tube part, features an 18650 battery coupled in a two-cell parallel series arrangement. This configuration provides an output of 8.4 volts with a capacity of 15.6 Amps. A battery management system (BMS) with two 20A cells regulates this battery, assuring safe use and recharge. This arrangement offers a consistent power supply and effective data handling for the monitoring system. To promote direct contact with water and speedy data collection, the temperature, pH, conductivity, and dissolved oxygen sensors are positioned at the bottom of the system. This positioning is critical for collecting real-time and exact readings of water quality parameters. The strategic placement of these sensors optimizes their exposure to water, boosting the accuracy of the obtained data.

3.2. Tool specification

The developed prototype contains a mix of sensors particulary chosen for monitoring water quality on the sea shore [31]. The parameters examined include pH level, temperature, salinity, and dissolved oxygen content, each crucial for evaluating marine water quality. Figure 7 demonstrates the development outcomes of the seawater quality monitoring instrument.

The tool’s design provides dependable and precise monitoring of crucial water quality indicators. The strong 4-inch PVC tube casing ensures durability in tough maritime situations. High accuracy readings are obtained by the integrated sensors, assuring the integrity of the monitoring system. The battery configuration provides longer operation with a consistent power source, governed by a BMS for safe and efficient recharge. The Specific characteristics of the seawater quality monitoring instrument are presented in Table 4.

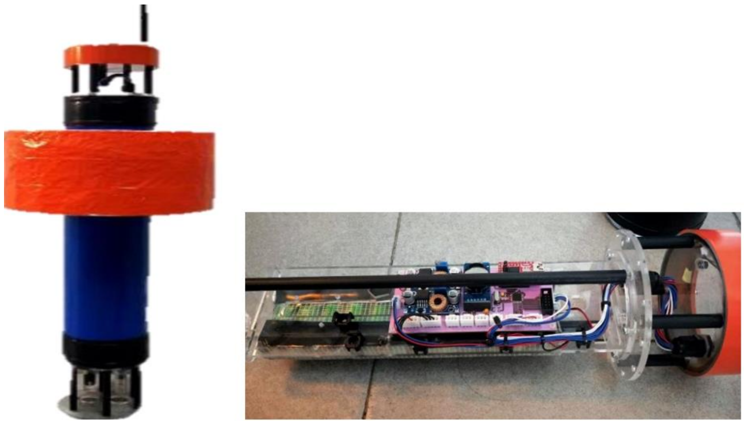

Figure 7. Development results of seawater quality monitoring tool

Table 4. Specification seawater quality monitoring tool

Specification	Description
Case tube	Diameter 4 inches and length/height 500 mm
Board	3 cm × 5 cm
Temperature range	-55 ºC to 125 ºC with an accuracy of ± 0.5 ºC
pH range	0 to 14 pH with an accuracy of ± 0.02 pH and a resolution of 0.01 pH
Dissolved oxygen concentration	0 to 20 mg/L (ppm) with an accuracy of ± 0.1 mg/L and a resolution of 0.01 mg/L
Electrical conductivity	0 to 20 mS/cm with sensor resolution ± 0.05
Battery	8.4 Volts / 15.6 Amps

3.3. Battery life testing

Battery life testing was done on the maritime coastal water quality monitoring system employing twelve Li-ion 4 batteries, each having a capacity of 2/2.5 Ah, rechargeable via a 2-cell 20-ampere BMS. Testing was carried out in the laboratory using an ammeter (in mAh) to measure the power consumption of each component and the turnigy charging power system to determine the remaining battery capacity. The predicted battery life was derived using (13).

$$T_{battery}(hour) = \frac{Battery\ Capacity\ (mAh)}{Load\ Current\ (mA)}\ x\ Efficiency \quad (13)$$

The findings in Table 5 demonstrate that the monitoring system uses more power, notably the GSM module, which demands greater power when the signal is poor. This greater power usage affects the total battery capacity. Under ideal signal circumstances, the battery lasts for roughly 119 hours or nearly 5 days. However, under tough signal circumstances, the battery life is decreased to around 86 hours or nearly 3.5 days. These results show the need of addressing signal circumstances in the implementation of the monitoring system. Efficient power management and future advancements in the GSM module might further prolong battery life, making the device more trustworthy for long-term surveillance in distant coastal locations.

Table 5. Result battery life testing

Component	Battery capacity	Power consumption per hour	
		Easy signal	Difficult signal
MCU + RTC module		0.01	0.01
Sensor ds18b20		0.05	0.05
Sensor pH		0.006	0.006
Sensor conductivity	15.6	0.01	0.01
Dissolved oxygen sensor		0.08	0.08
GSM mode		0.05	0.1
Modul micro-SD card		0.02	0.02
GPS mode		0.03	0.03
Total power usage		0.236	0.306
Batterylife (hours)		119.08	86.19

3.4. Comparison with conventional measurement

The primary objective of this research is to evaluate the precision of the sensors used in the water quality monitoring system [32]. The measurements were conducted by comparing the data acquired from the multiple-parameter sensor (MPS) with the monitoring system of the Blynk platform. Each sensor underwent many rounds of testing, with data being collected at five-minute intervals across a predetermined timeframe. This method guarantees the dependability and uniformity of the measurements [33]. The findings from these tests are shown in Table 6.

Table 6. Comparison sensor analysis result of monitoring and MPS

Sensor	Error (%)		Standard error		Accuracy (%)		Standard deviation	
	MPS	Monitoring	MPS	Monitoring	MPS	Monitoring	MPS	Monitoring
Temperature	9.75	9.5	0.195	0.155	88	90.5	0.39	0.35
pH levels	7.33	6.3	0.117	0.083	90.6	93.67	0.212	0.197
Dissolved oxygen concentration	5.75	5	0.062	0.055	94.85	96.82	0.277	0.246
Electrical conductivity	11	6.5	0.29	0.285	89	93.50	0.677	0.635

The data presented in Table 6 clearly illustrates the monitoring system's exceptional precision and lower rates of error when compared to the traditional MPS. Our study corroborates the findings of Zhang *et al.* [4] on the enhanced accuracy achieved through the utilization of IoT-based systems. Furthermore, our research expands upon these findings by incorporating the simultaneous monitoring of temperature, electrical conductivity, and dissolved oxygen. The system's durability and precision in various water conditions make it an excellent choice for continuous monitoring of coastal water quality. The IoT-based system provides improved precision and the ability to collect data in real-time, which offers substantial benefits compared to conventional approaches. These advantages contribute to more efficient environmental management and decision-making processes.

3.5. Data observation and analysis

Data gathered from the four sensors used to monitor water quality on the sea shore were viewed using the Blynk platform, which analyzes temperature, pH levels, electrical conductivity, and dissolved oxygen levels. Tests were done on swimming pool water under two distinct conditions: in the morning and during the day. Data were gathered every 5 minutes to examine changes over time. This comparison was done between the sensor outputs monitored by Blynk and the measures collected from the MPS.

Figure 8 demonstrates the execution of the water quality monitoring instrument under morning settings. The equipment is put in a swimming pool, imitating a controlled environment for precise data collecting. The system's real-time data transmission capabilities are exhibited via the Blynk platform, which displays the gathered data for remote monitoring. Figure 9 provides the outcomes of data observation from the morning testing. The figures exhibit the readings of temperature, pH levels, electrical conductivity, and dissolved oxygen levels with time, as recorded by the Blynk platform and compared with the MPS. The strong connection between the two sets of data verifies the correctness of the monitoring technology.

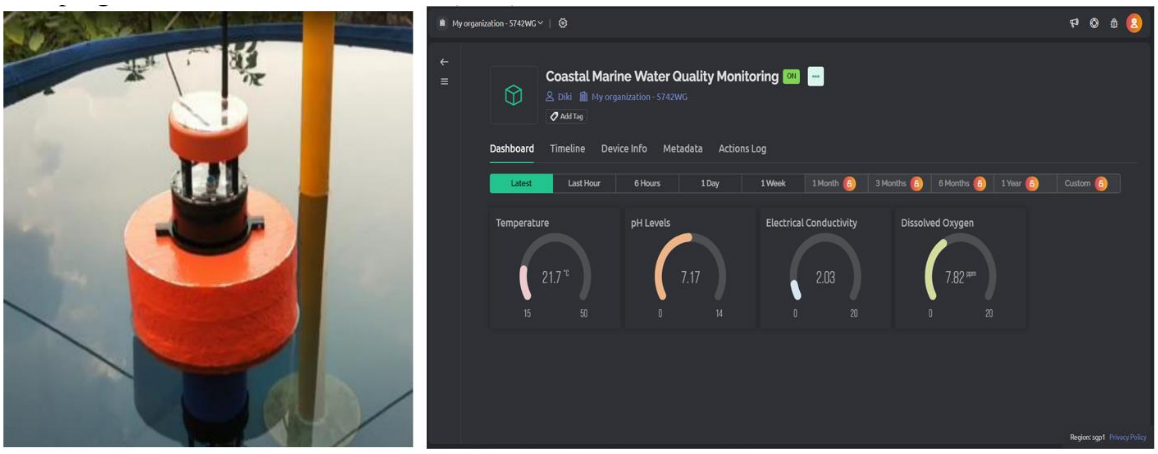

Figure 8. Implementation and monitoring of tools in morning conditions

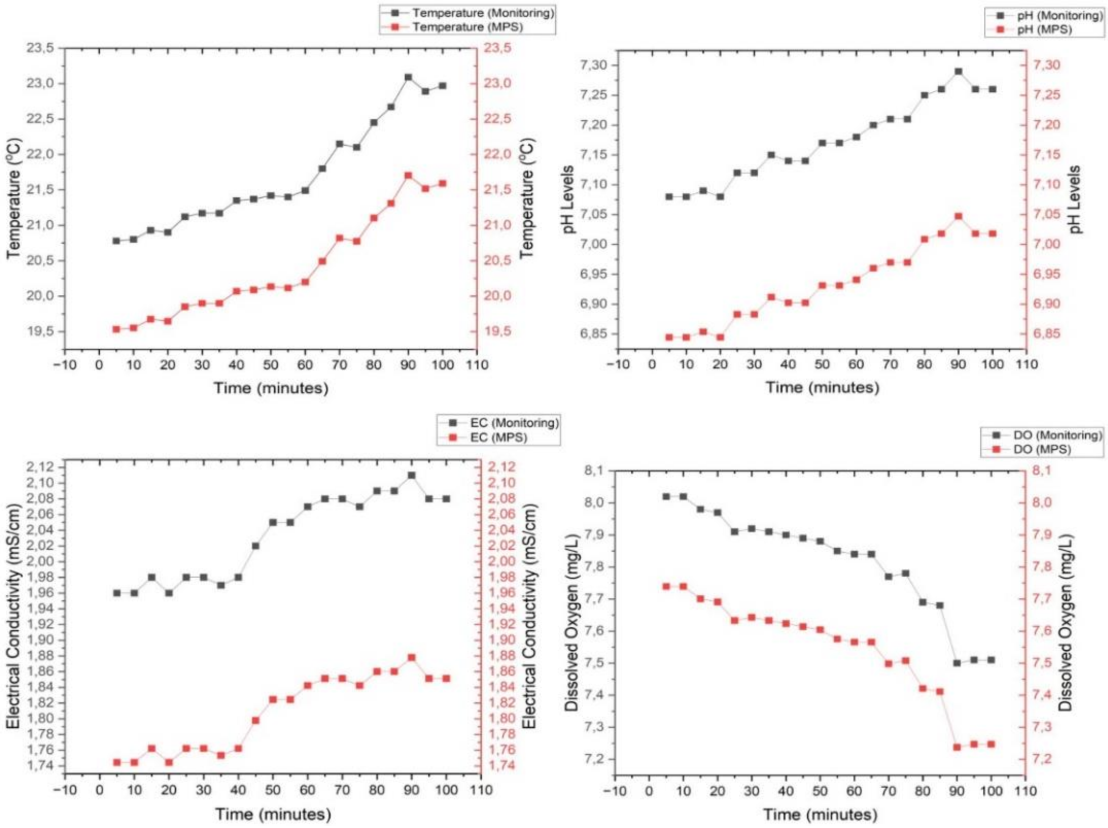

Figure 9. Result data observation of tools in morning conditions

Figure 10 depicts the application of the monitoring tool in the afternoon, illustrating its flexibility to various times of day and environmental circumstances. The tool continues to communicate real-time data to the Blynk platform, preserving its usefulness and accuracy. Figure 11 provides the outcomes of data observation from the afternoon testing. Similar to the morning testing, the graphs demonstrate the observations of temperature, pH levels, electrical conductivity, and dissolved oxygen levels with time. The data from the Blynk platform and MPS reveal consistent findings, validating the tool's accuracy.

Nevertheless, the discrepancies in the acquired figures are primarily caused by slight sensor imperfections and anomalies in data transmission across cellular networks. The system's reliability may be compromised in remote or signal-challenged areas due to its dependence on cellular networks. In addition, the sensor's performance may differ in more severe or turbulent maritime circumstances, which were not thoroughly examined in this study. Notwithstanding these obstacles, the results illustrate the effectiveness of the monitoring device in providing accurate and immediate water quality data, which is crucial for the sustainable management of marine ecosystems.

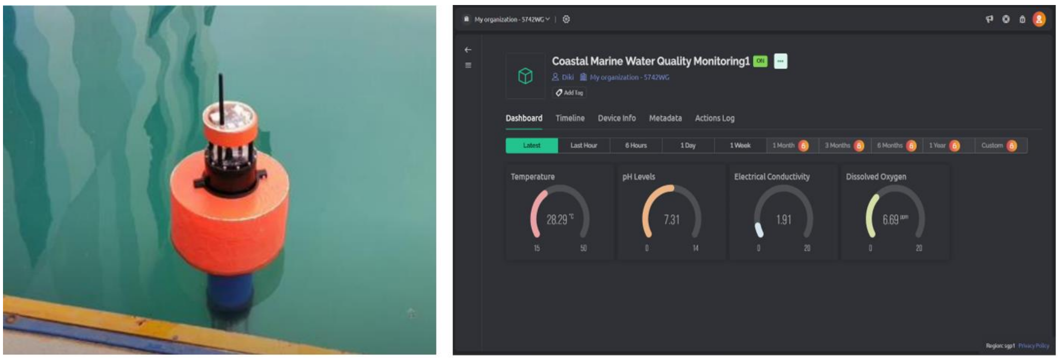

Figure 10. Implementation and monitoring of tools in afternoon conditions

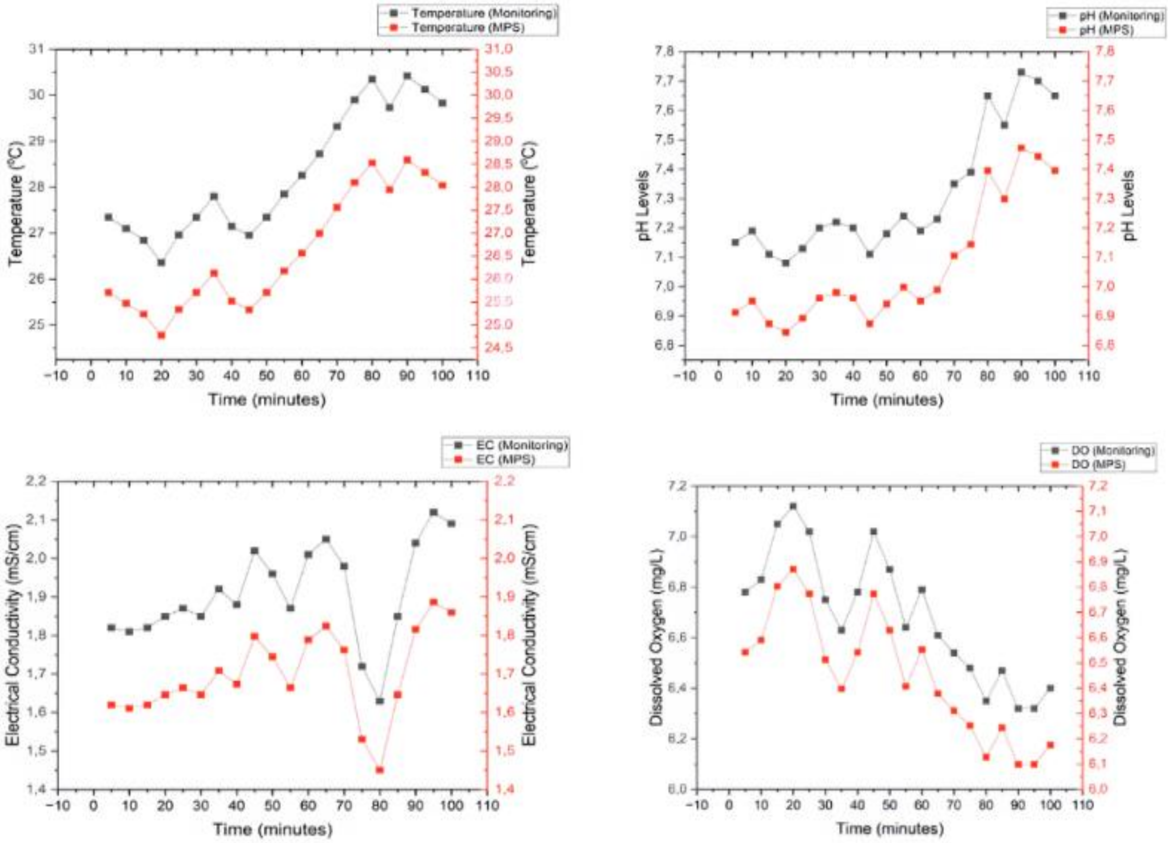

Figure 11. Result data observation of tools in afternoon conditions

The integration of the Blynk platform into the coastal marine water quality monitoring system represents a notable advancement in the field of real-time environmental monitoring. The system's greater precision and dependability, as proven by comparisons with older methods, enable more accurate and consistent monitoring of temperature, pH levels, electrical conductivity, and dissolved oxygen. This is vital for effective marine ecosystem management and informed conservation decisions. The system's real-time data transmission and multi-parameter monitoring decrease the need for extensive fieldwork, saving time and resources. Its rugged design and excellent energy management mean it can function in isolated and harsh maritime situations. Future research could improve the system's capabilities by adding sensors for pollutants like nitrates and phosphates and applying machine learning for predictive water quality assessments. These developments will further strengthen the system's contribution to SDGs, enabling long-term marine ecosystem sustainability.

4. CONCLUSION

The creation of an IoT-based coastal water quality monitoring system signifies a significant improvement in environmental monitoring technology. Integrated with the Blynk platform, this instrument offers real-time data gathering for major water quality parameters, temperature, pH, electrical conductivity, and dissolved oxygen with excellent precision (90.5%, 93.67%, 93.50%, and 96.82%, respectively). Our findings give strong evidence that this approach is not only reliable but also scalable for continuous water quality evaluation, which is vital for protecting marine ecosystems and public health.

This research contributes to environmental science by giving a practical and effective method for water quality monitoring that matches with SDGs, particularly those connected to climate action and life below water. The tool's high precision and real-time capabilities make it relevant for stakeholders and policymakers, creating a basis for future developments in sustainable monitoring technologies. Future study could expand this system to incorporate new factors or apply it in diverse aquatic ecosystems, thus strengthening its significance in environmental preservation and human well-being in the digital era.

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