Complex Systems Informatics and Modeling Quarterly (CSIMQ)
eISSN: 2255-9922
Published online by RTU Press, https://csimq-journals.rtu.lv
Article 239, Issue 43, June/July 2025, Pages 77–86
https://doi.org/10.7250/csimq.2025-43.05

Internet of Things Enabled Low-Cost and Portable Multi-Parameter Water Quality Testing System for Environmental Monitoring Applications

Pooja N. Sawant[1], Ganesh S. Nhivekar[2], Sachin S. Panhalkar[3,4], Rajanish K. Kamat[5], Yojana Y. Patil[*,1], and Tukaram D. Dongale[1,6,*]

[1] School of Nanoscience and Biotechnology, Shivaji University, Kolhapur, 416004, India
[2] Department of Electronics, Yashavantrao Chavan Institute of Science, Satara, 415001, India
[3] Department of Geography, Shivaji University, Kolhapur, 416004, India
[4] Center for Climate Change and Sustainability Studies, Shivaji University, Kolhapur, 416004, India
[5] Dr. Homi Bhabha State University, 15, Madam Cama Road, Mumbai, 400032, India
[6] Functional Materials and Materials Chemistry Laboratory, Department of Physiology, Saveetha Dental College & Hospitals, Saveetha Institute of Medical & Technical Sciences, Saveetha University, Chennai, 600077, Tamil Nadu, India

pns.rs.nano@unishivaji.ac.in, drgsnhivekar@ycis.ac.in, ssp_geo@unishivaji.ac.in, rkk_eln@unishivaji.ac.in, yyp.snst@unishivaji.ac.in, tdd.snst@unishivaji.ac.in

Abstract. Monitoring and testing of different water parameters play a vital role in water safety. The traditional analytical instruments of water testing are labor-intensive, require trained staff, and are difficult to operate in the field, owing to their non-portability. Considering these issues, the present work reports the development of an Internet of Things (IoT) enabled low-cost multi-parameter water testing system. The proposed system can measure the turbidity, pH, temperature, and conductivity properties of water samples. The proposed system was developed around a low-cost Arduino UNO R3 microcontroller. The system was designed in such a way that it can operate on a 12V rechargeable battery. Therefore, the system can be moved to the field, and important water parameters can be measured. The total cost of the entire system was comparatively low, suggesting the proposed system can be used by economically weak communities. The system was tested with real water samples, and the results are compared with commercial water parameters testing systems. The results of the proposed system are well in agreement with the commercial systems, suggesting its effectiveness for on and off-field water analysis of resource-limited areas.
Keywords: Water Quality; Environment; Sensors; Microcontroller; IoT.

[*] Corresponding author

Reference: P. N. Sawant, G. S. Nhivekar, S. S. Panhalkar, R. K. Kamat, Y. Y. Patil, and T. D. Dongale, "Internet of Things Enabled Low-Cost and Portable Multi-Parameter Water Quality Testing System for Environmental Monitoring Applications," Complex Systems Informatics and Modeling Quarterly, CSIMQ, no. 43, pp. 77–86, 2025. Available: https://doi.org/10.7250/csimq.2025-43.05

Additional information. Author ORCID iD: G. S. Nhivekar – https://orcid.org/0000-0002-6616-6586, R. K. Kamat – https://orcid.org/0000-0002-5779-2614, Y. Y. Patil – https://orcid.org/0000-0002-0765-8310, and T. D. Dongale – https://orcid.org/0000-0003-2536-6132. PII S225599222500239X. Received: 28 November 2024. Accepted: 4 May 2025. Available online: 31 July 2025.

1 Introduction

The growth of the global economy and advancements in technology in recent years have led to increased concerns about the environment, with a particular focus on the state of aquatic ecosystems worldwide [1]. Approximately 97% of the Earth's water is not for direct consumption due to its high salt content. However, the remaining freshwater sources are being greatly impacted by factors such as population growth, urbanization, and industrialization in many countries. Water pollution has severe consequences for public health, resulting in roughly 14,000 deaths per day worldwide [2]. As a growing environmental issue, water pollution has become a global concern due to the limited availability of fresh water. Wastewater containing heavy metals, pharmaceutical waste, and various types of contaminants poses significant risks to both the environment and public health. Current monitoring methods are often complex, time-consuming, and require trained professionals, making them less practical [3].

In recent years, a lot of efforts have been devoted to developing low-cost and portable water analysis systems. In recent years, microfluidic devices have emerged as a promising solution for creating a portable, highly sensitive, and selective water quality control system [4]. Glanc-Gostkiewicz et al. have done a comparative study of laboratory pH systems and portable pH systems, resulting in cost-effective, easy-to-handle, and portable water testing systems [5]. Various research groups have developed water testing systems. For instance, Salmeron et al. developed a colorimetric sensor-based electronic monitoring system using 3D printing technology to detect micro-organisms [6]. Nag et al. developed a system for salinity testing for marine applications [7]. Very few works are available that report a simultaneous measurement of two or more water quality factors. On-site testing of water parameters such as turbidity, pH, temperature, and conductivity is pivotal for real-time quality assessment. These are fundamental parameters that significantly influence many other factors [8]. Therefore, accurate and timely measurements of these parameters are essential. The integration of IoT for monitoring these parameters further enhances the effectiveness of the system by enabling continuous, remote data collection and real-time analysis. This ensures timely detection of changes in water quality, improves decision-making, and allows for prompt action, especially in areas where traditional testing methods may be slow or unavailable. Moreover, it can be a difficult task to analyze water samples from remote catchment areas due to the distance between testing sites and laboratories, which can lead to errors in testing and inaccurate results. Therefore, there is a need to develop low-cost and portable water quality testing systems.

Considering this need, in this article, we present a microcontroller and Internet of Things (IoT) based water quality testing system. We designed and developed this system to measure the turbidity, pH, temperature, and conductivity properties of water samples. The proposed system is a low-cost and portable solution for measuring essential water parameters in the field, developed using an Arduino UNO R3 microcontroller, an IoT module, sensors, and a 12 V rechargeable battery. The system was tested using real water samples and found to be in good agreement with commercial water testing systems, suggesting its effectiveness for on and off-field water analysis in resource-limited areas.

The article is structured as follows. The proposed testing system is presented in Section 2, where its components and functionality are discussed. The results of the application of the system are presented in Section 3. Discussion of the results, including the limitations of the proposed system, is available in Section 4. Section 5 concludes the article.

2 Design and Development of Multi-Parameter Water Quality Testing System

In the present work, we have used a low-cost and open-source Arduino UNO R3 microcontroller to develop the multi-parameter water quality testing system. In particular, we tried to measure the turbidity, pH, temperature, and conductivity properties of water samples. The block diagram of the system is shown in Figure 1. The DFRobot turbidity sensor was used to detect water quality in terms of turbidity [9]. The sensor consists of an Infrared Light-Emitting Diode (LED) as the transmitter and an Infrared detector as the receiver. The turbidity sensor produces an analog output voltage, which depends on the amount of Total Suspended Solids (TSS) in water. As the TSS increases in liquid, the turbidity level increases, and thereby the output voltage of the sensor decreases. The output voltage of the turbidity sensor was interfaced to the on-chip 10-bit Analog-to-Digital Converter (ADC) of the Arduino UNO R3 microcontroller, which was further used to map voltage in terms of turbidity.

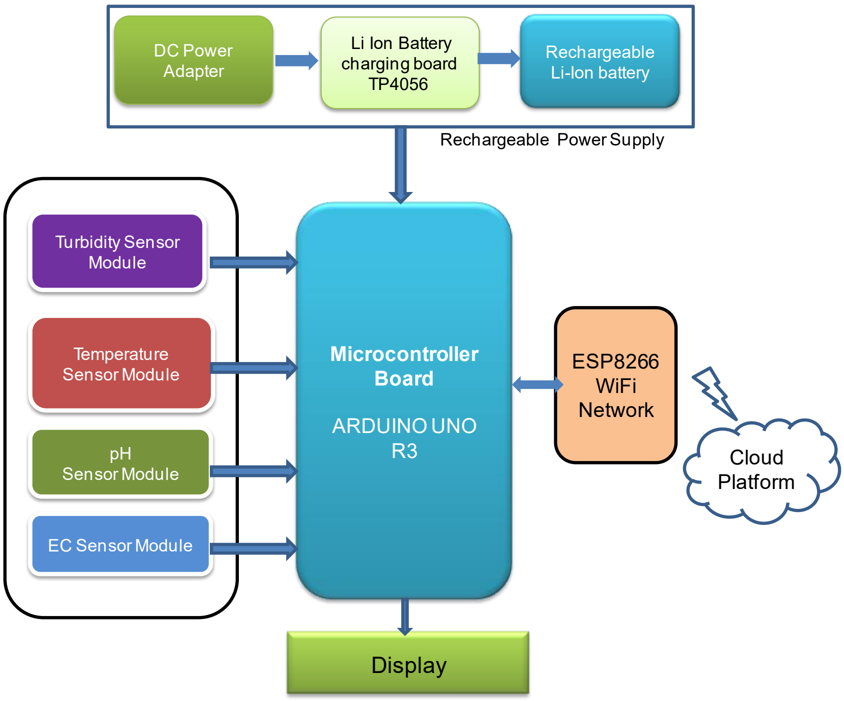

Figure 1. Block diagram of a multi-parameter water quality testing system

In the case of temperature measurement, the digital DS18B20 temperature sensor was used [10]. The DS18B20 temperature has a 1-wire interface to the microcontroller. In other words, it requires only one digital pin for half-duplex communication. Hence, it reduces the input-output pin connections with the microcontroller and thereby reduces the complexity of the system. The DS18B20 temperature sensor is water resistant and can measure temperatures from –55 °C to +125 °C with ±0.5 °C accuracy. The Total Dissolved Solids (TDS) sensor module was used to measure the electrical conductivity and TDS of water. The sensor is able to measure the TDS up to 1000 ppm. The sensor consists of two electrodes that measure the electric charge flowing through the water. The electric charge of water increases as total dissolved solids increase, which is used to calculate the total dissolved solids in ppm (mg/L). The analog pH sensor module was interfaced with the analog input pin of the Arduino UNO R3 microcontroller to measure the pH of water. The pH sensor module is able to measure the pH in the range of 0 to 14. To get accurate results, the pH sensor module was recalibrated in the laboratory with the help of a known pH buffer solution. To calibrate the pH sensor, the output voltage of the sensor is recorded for the standard buffer solutions, namely 4 pH, 7 pH, and 9.2 pH. The corresponding voltage shows a linear relationship with the pH value.

The circuit diagram of the developed system is shown in Figure 2. Arduino Uno R3 microcontroller interprets the different parameters from the sensors and displays the result on a Liquid Crystal Display (LCD). The Arduino Uno R3 microcontroller was programmed with Embedded-C language within the Arduino Integrated Development Environment (IDE). It should be noted that the PC/laptop should have an Arduino driver(s)[†]. If a PC/laptop is installed with Arduino IDE, then it is not required to install a separate driver(s).

The implemented code flowchart is shown in Figure 3. The proposed system uses the ThingSpeak (Mathworks) IoT platform that allows data to be sent and received automatically. Arduino Uno R3 microcontroller reads the different parameters from the sensors and posts the sensor readings to the cloud with the help of an IoT module (ESP8266 Wi-Fi module). The ESP8266 Wi-Fi module enables the microcontroller to connect to the internet through a predefined hotspot within range. The users can remotely monitor this data in graphical form on the ThingSpeak IoT platform. In the typical process, when a power supply is switched ON, the system is initialized with the necessary on-chip hardware resources. The linear power supply provides a stable voltage of 12 V. Arduino Uno R3 microcontroller connects to the network through a predefined hotspot within range. The system monitors the turbidity, pH, temperature, and conductivity of liquid samples, and these results are displayed on an LCD screen. For continuous monitoring, the results are refreshed every 5-second intervals. This way, we can have the exact results of each sensor.

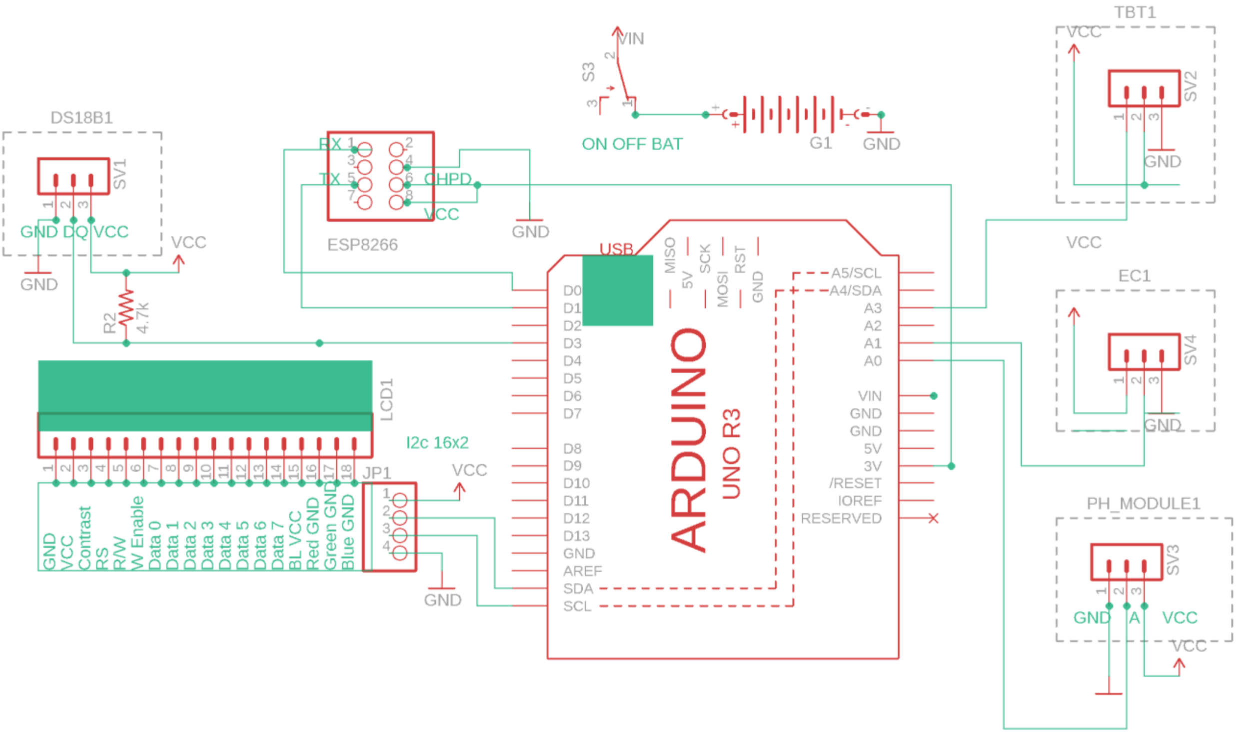

Figure 2. Circuit diagram of a multi-parameter water quality testing system

To house all the electronic components, the interface, and the sensors with a microcontroller, we developed a suitable box (custom enclosure) using 3D printing technology. For the fabrication of the 3D printed box, we used a bio-derived Poly-Lactic Acid (PLA) polymer for 3D printing. The box was made using an ACCUCRAFT i250 3D printing machine. The 3D-printed box was designed in the Solid Edge software 2022 student edition in stereolithography (STL) format.

Table 1 summarizes the details of each electronic component, including their cost in 2025. The proposed multi-parameter water quality testing system is more cost-effective than conventional water quality testing[‡], even using systems of lower capabilities. Such a cost-effective integrated water quality testing approach is especially beneficial for resource-limited communities.

[†] This driver(s) can be found at: https://www.arduino.cc/en/software. For more information, visit https://docs.arduino.cc/tutorials/generic/DriverInstallation.

[‡] For instance, see https://mytapscore.com/?srsltid=AfmBOorGVijoPf7O1wOvZaK9ibeNjWPiGU7XbtOFPmJ5kuJOQeQlIbBi or https://www.unitywater.com/business/accounts-and-billing/pricing-fees-and-charges/laboratory-services

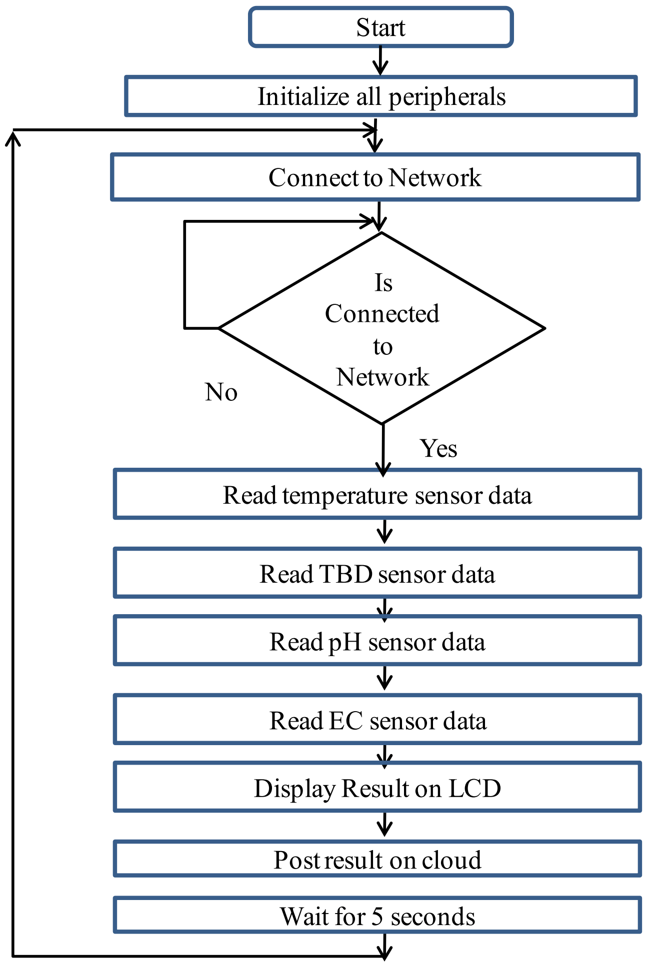

Figure 3. Flowchart of the system's functionality cripted in the Arduino IDE

Table 1. Components of the proposed system

Sr. No.	Parts	Type and Description	Cost (USD)
1.	Arduino UNO board	Arduino UNO R3 development board	8
2.	LCD Display Module	16x2 LCD with I2C interface	3
3.	Temperature Sensor Probe	DS18B20 waterproof temperature sensor probe	1
4.	pH Sensor Module	DFRobot Analog output pH Sensor module	22
5.	TDS Sensor Module	Analog signal output TDS sensor module	13
6.	Turbidity Sensor Module	DF robot analog signal output turbidity sensor module measuring range: 0 to 1000 NTU.	10
7.	AC-DC power converter	12 V 1A, AC-DC power adaptor for charging a rechargeable battery	1.50
8.	18650 rechargeable battery	18650 rechargeable battery 1000 mAh (3)	3
9.	Breadboard Jumpers	Male to male 10 Pcs, male to female 10 Pcs, female to female 10 Pcs	1.85
10.	Toggle Switch	On-Off toggle switch / 3-pin 2-Way SPDT switch, 3A at 230VAC and 6A at 125VAC (2)	0.25
11.	Custom Enclosure	3D-printed custom enclosure	7.5
12.	Arduino Uno cable	USB A to B cable 50cm for UNO R3 and PC interface	0.75
13.	ESP8266	Wi-Fi module	3
Total Cost in USD			**74.85**

3 Results

The usefulness of the system was tested by measuring the turbidity, pH, temperature, and conductivity properties of water samples. For this, soil samples were collected from the Shivaji University, Kolhapur campus. For testing purposes, five water samples were made by adding 0.5 g, 1 g, 1.5 g, 2 g, and 2.5 g of soil into 80 ml of distilled water, as shown in Figure 4. The soil was dissolved in the distilled water by mixing it thoroughly to get a measurable consistency. Finally, the turbidity, pH, temperature, and conductivity properties of each sample were measured. For comparison purposes, the turbidity, pH, temperature, and conductivity properties of these five water samples were tested by using commercial instruments.

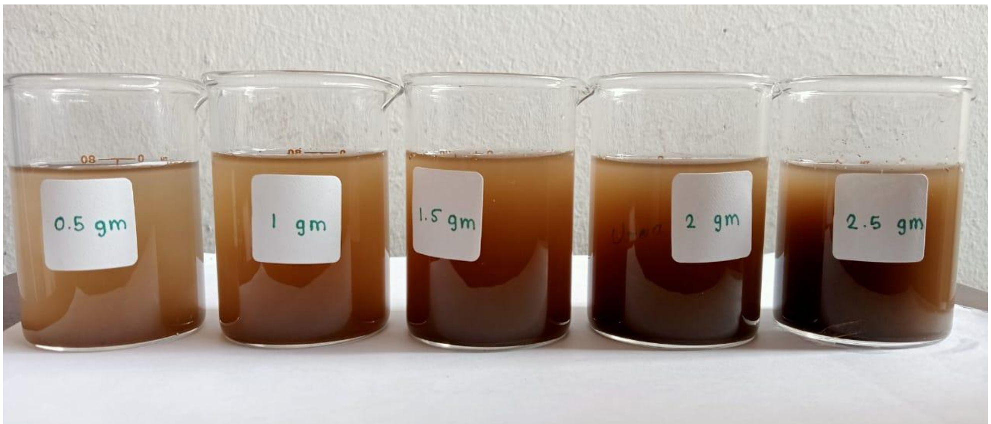

Figure 4. Soil samples with a soil ratio of 0.5 gm to 2.5 gm in 80 ml of distilled water

Initially, all 5 samples were tested on the standard turbidity instrument (Digital turbidimeter model EQ811, EQUIPTRONICS), which is based on spectrophotometer theory. The spectrophotometer was calibrated as per the manufacturer's manual for turbidity measurement. This spectrophotometer was calibrated with distilled water as a blank sample and then with standard solutions of 40 NTU and 400 NTU. The frequency and wavelength measured from this instrument are up to 50 Hz and 850 nm, respectively. In the next stage of the work, the turbidity of all 5 samples was tested on our proposed multi-parameter water quality testing system. The turbidity sensor module utilized in this work measures the turbidity in the range of 0 to 1000 NTU. To minimize the handling and system errors, all the samples were tested in triplicate. Likewise, the pH of all five samples was measured using a commercial system and our proposed system. All the samples were tested on a commercial digital pH meter (DBK, 10PHM01). This pH meter was used to identify the acidity or alkalinity of testing samples. For the final analysis, the commercial system was calibrated for 4.0, 7.0, and 9.2 pH as per the manufacturer's manual. The DF Robot analog output pH sensor module was used to measure the pH of all five samples. In this case, also, the samples were also tested in triplicate.

Electrical Conductivity can give an indication of the comprehensive amount of ionic content or nutrients available in the soil. In the case of conductivity and temperature measurements, the commercially available conductivity and temperature measurement system (VSI–04ATC) was used. Initially, the commercial conductivity meter was calibrated as per the manufacturer's specification for conductivity calculation (0.996 E_c). The conductivity of five samples was measured in triplicate using a commercial system and the proposed multi-parameter water quality testing system. In the case of temperature measurement, the DS18B20 waterproof temperature sensor probe was used. This probe can measure temperatures from –55 °C to +125 °C with ±0.5 °C accuracy. The temperature of five samples was measured in triplicate using a commercial temperature sensor probe and the proposed multi-parameter water quality testing system.

To validate the effectiveness of the proposed system, we have plotted the turbidity, pH, temperature, and conductivity readings of the developed system and the standard commercial system, as shown in Figure 5. The results asserted that the turbidity, pH, temperature, and conductivity readings of the developed system and standard system are in close agreement with each other. For each case, the experimental data were well-fitted using linear equations and had high Adjusted R^2 values (> 0.99). These results suggested that our proposed multi-parameter water quality testing system can work effectively and efficiently to measure critical water parameters.

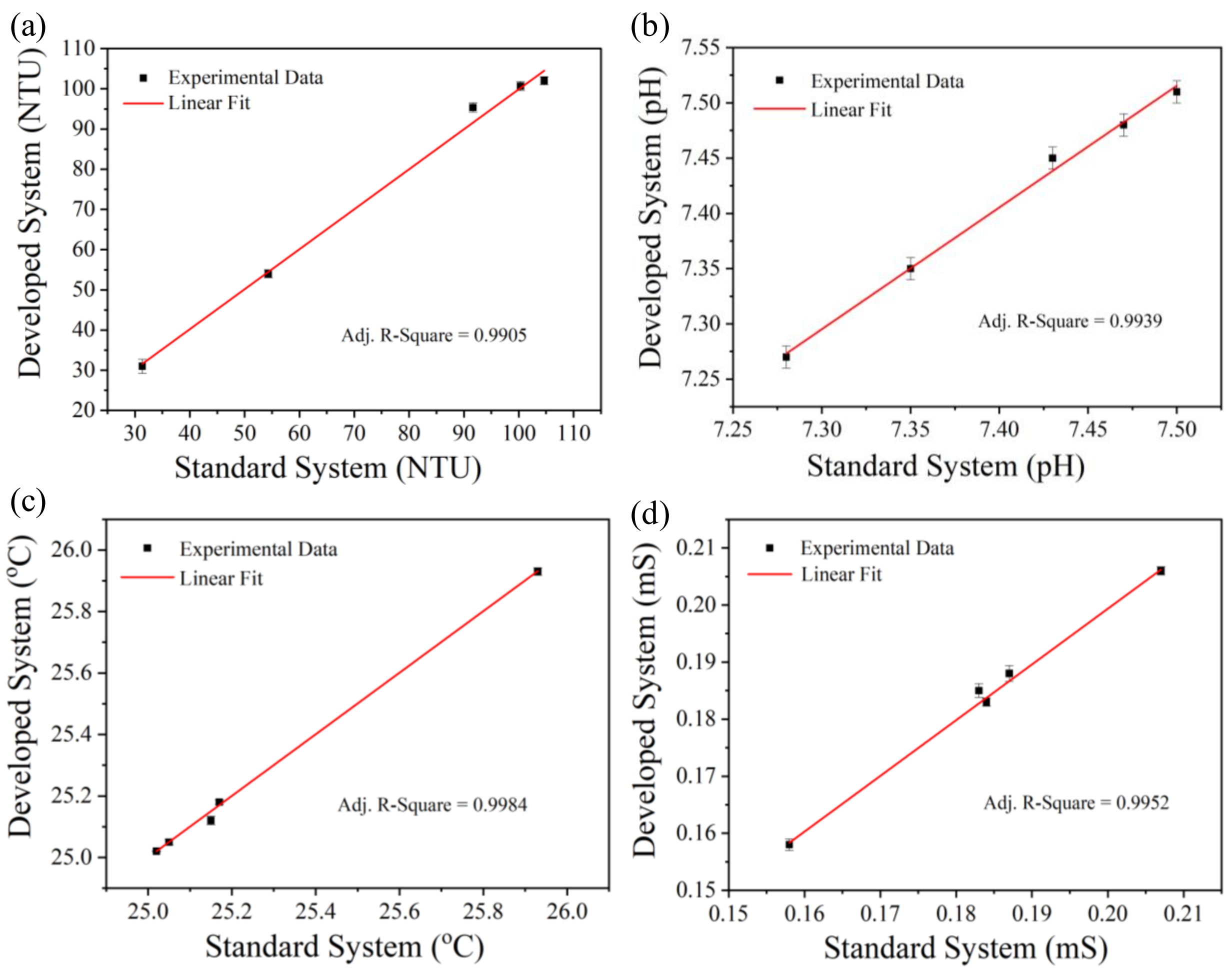

Figure 5. Validation of (a) turbidity, (b) pH, (c) temperature, and (c) conductivity measurements between the developed system and the standard system

For quantitative assessment, we have calculated the percentage error of measurements using Equation 1 [11].

$$\%\ Error = \left|\frac{M_{DS}-M_{CS}}{M_{CS}}\right| \text{ x } 100\ , \tag{1}$$

where M_{DS} refers to the measurement results of the developed system, and M_{CS} refers to the measurement results of the standard commercial system. The average percentage error (average of five samples) of the measurements was found to be 1.7% (turbidity), 0.1% (pH), 0.02% (temperature), and 0.5% (conductivity). The average percentage of errors is very small for each case. This suggests that the proposed multi-parameter water quality testing system can be used for the measurement of turbidity, pH, temperature, and conductivity properties of water samples for different environmental assessments.

The field measurement photographs and IoT dashboard results are shown in Figures 6a and 6b, respectively. During the test, it was observed that the developed system works well in field measurements. These results asserted that the proposed IoT-enabled low-cost multi-parameter water quality testing system can be used for water quality assessment.

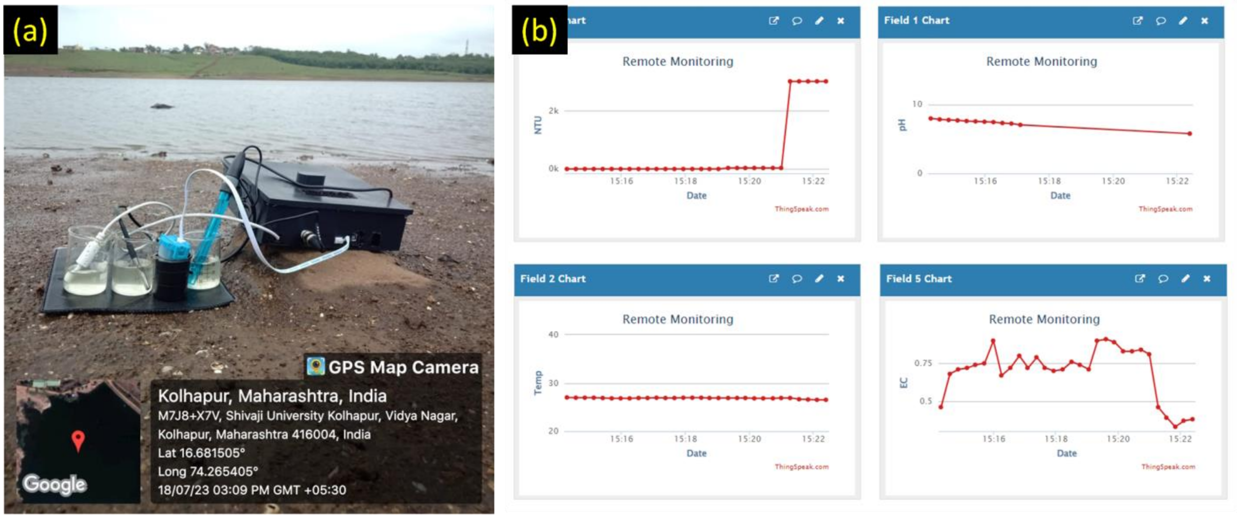

Figure 6. (a) The field measurement photographs and (b) IoT dashboard results of the proposed system

4 Discussion

The objective of this study was to show the effectiveness of a low-cost multi-parameter water quality testing system developed using microcontrollers and IoT technology. The system was tested by measuring four critical water quality parameters, such as turbidity, pH, temperature, and conductivity. Soil was added to water in varying amounts to create samples with differing turbidity levels. This allowed for a detailed comparison between the developed system and commercial testing instruments. The results showed that the proposed system closely matched the measurements obtained from commercial systems, confirming its capability to accurately assess water quality parameters. For the four parameters, the measurements obtained using the proposed system were in close agreement with those from the commercial instruments, as shown in Figure 5. Linear regression analyses of the data showed high adjusted R^2 values (>0.99) for each parameter. The numeric analysis (Figure 5) of the percentage error revealed small deviations between the readings of the developed system and the commercial system. The average percentage errors for turbidity, pH, temperature, and conductivity were found to be 1.7%, 0.1%, 0.02%, and 0.5%, respectively. This shows the accuracy of the developed system and suggests that it can accurately replicate the performance of commercial systems. The low error highlights that the developed system can provide accurate and reliable water quality measurements. These low error rates are pivotal for ensuring that the system can be used confidently for monitoring and assessing water quality, and, due to its comparatively low cost, can meet the water testing needs also in resource-limited areas.

The system was also tested under field conditions, and its performance remained consistent, as evidenced by the field photographs and IoT dashboard results (Figures 6a and 6b). This further indicates that the system is not only reliable in laboratory settings but also functional in real-world, outdoor applications where traditional water testing equipment might be too expensive, unavailable, and not portable. The findings from this study suggest that the developed IoT-based water quality testing system is a viable, cost-effective alternative to commercial systems for measuring key water quality parameters. The low percentage error, combined with the system's portability and affordability, makes it a potent tool for environmental monitoring, especially in regions where access to commercial water quality testing equipment is limited. The successful implementation of this system could potentially enable better water quality assessments in underdeveloped and economically disadvantaged areas, contributing to improved water management and environmental conservation efforts.

The presented research work demonstrates a significant advancement in low-cost, IoT-enabled water quality testing; however, it has some limitations. First, the system is restricted to measuring only four water quality parameters, namely turbidity, pH, temperature, and conductivity, which leaves out other critical parameters such as dissolved oxygen and microbial content. Second, the accuracy of the system as compared to the commercial instruments shows slight deviations, which may be critical in high-precision applications. Third, the performance of the system under prolonged field usage remains untested. Lastly, the reliance on the open-source Arduino UNO R3 may limit scalability and compatibility with advanced IoT platforms in future developments. Despite these limitations, the present work offers several benefits, including affordability, portability, and ease of use, making it a suitable solution for resource-limited settings.

5 Conclusion

In conclusion, we successfully demonstrated the use of microcontrollers and IoT for the multi-parameter water quality testing system. Our system is capable of measuring the turbidity, pH, temperature, and conductivity properties of water samples in laboratory and field settings. Therefore, the present system can be used by hobbyists and environmentalists in their research. The total cost of the entire system was relatively small, suggesting the presented system can be used by economically weak communities. The system was tested on real water samples, with the results being compared with the standard commercial water parameters testing systems. The percentage error of the measurements was found to be 1.7% (turbidity), 0.1% (pH), 0.02% (temperature), and 0.5% (conductivity). The low value of percentage errors and cost-effectiveness suggested that the proposed system can be also used for water quality assessment in resource-limited areas.

Acknowledgment: Dr. Ganesh S. Nhivekar and Prof. Sachin S. Panhalkar would like to thank the Science and Engineering Research Board (DST-GoI) for providing the research grant through the State University Research Excellence (SERB–SURE) scheme (SUR/2022/002981). The authors would like to thank the RUSA-Maharashtra for the financial assistance under the 'RUSA-Industry Sponsored Centre for VLSI System Design.'

Data availability statement: The data that supports the findings of this study are available upon request from the authors.

Competing interests: The authors declare no competing interests.

References

[1] B. K. Mishra, P. Kumar, C. Saraswat, S. Chakraborty, and A. Gautam, "Water security in a changing environment: Concept, challenges and solutions," *Water*, vol. 13, no. 4, article 490, 2021. Available: https://doi.org/10.3390/w13040490

[2] N. A. Mailloux, C. P. Henegan, D. Lsoto, K. P. Patterson, P. C. West, J. A. Foley, and J. A. Patz, "Climate solutions double as health interventions," *International Journal of Environmental Research and Public Health*, vol. 18, no. 24, article 13339, 2021. Available: https://doi.org/10.3390/ijerph182413339

[3] D. R. Prapti, A. R. Mohamed Shariff, H. Che Man, N. M. Ramli, T. Perumal, and M. Shariff, "Internet of Things (IoT)-based aquaculture: An overview of IoT application on water quality monitoring," *Reviews in Aquaculture*, vol. 14, no. 2, pp. 979–992, 2022. Available: https://doi.org/10.1111/raq.12637

[4] P. K. Rai, M. Islam, and A. Gupta, "Microfluidic devices for the detection of contamination in water samples: A review," *Sensors and Actuators A: Physical*, vol. 347, article 113926, 2022. Available: https://doi.org/10.1016/j.sna.2022.113926

[5] M. Glanc-Gostkiewicz, M. Sophocleous, J. K. Atkinson, and E. Garcia-Breijo, "Performance of miniaturised thick-film solid state pH sensors," *Sensors and Actuators A: Physical*, vol. 202, pp. 2–7, 2013. Available: https://doi.org/10.1016/j.sna.2013.04.012

[6] J. F. Salmeron et al., “Portable electronic system for fast detection of bacteria lactase fermentation in water samples,” *Sensors and Actuators A: Physical*, vol. 338, article 113486, 2022. Available: https://doi.org/10.1016/j.sna.2022.113486

[7] A. Nag, S. C. Mukhopadhyay, and J. Kosel, “Sensing system for salinity testing using laser-induced graphene sensors,” *Sensors and Actuators A: Physical*, vol. 264, pp. 107–116, 2017. Available: https://doi.org/10.1016/j.sna.2017.08.008

[8] M. M. M. Syeed, M. S. Hossain, M. R. Karim, M. F. Uddin, M. Hasan, and R. H. Khan, “Surface water quality profiling using the water quality index, pollution index and statistical methods: A critical review,” *Environmental and Sustainability Indicators*, vol. 18, pp. 2–23, 2023. Available: https://doi.org/10.1016/j.indic.2023.100247

[9] DFRobot, “Gravity: Analog pH Sensor/Meter Kit V2.” Available: https://dfimg.dfrobot.com/nobody/wiki/8e585d98aafe2bab22be39c5b68165c5.pdf. Technical notes: https://www.analog.com/media/en/technical-documentation/data-sheets/ds18b20.pdf

[10] Analog Devices, “DS18B20: Programmable Resolution 1-Wire Digital Thermometer.” Available: https://www.analog.com/media/en/technical-documentation/data-sheets/ds18b20.pdf.

[11] G. S. Nhivekar, S. R. Jagdale, S. B. Kamble, B. T. Jadhav, R. K. Kamat, and T. D. Dongale, “Versatile Three-in-One Single Beam Visible Colorimeter for Undergraduate Chemistry Laboratories,” *Journal of Chemical Education*, vol. 99, no. 11, pp. 3765–3772, 2022. Available: https://doi.org/10.1021/acs.jchemed.2c00372