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Research Article

Performance Evaluation of a NodeMCU-Based Smart System for Monitoring Total Dissolved Solids in Diverse Water Sources

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Abstract - Continuous monitoring of water quality is essential for protecting public health and ensuring environmental sustainability. This study presents the design and preliminary assessment of a low-cost Internet of Things (IoT)-based monitoring prototype developed to measure Total Dissolved Solids (TDS) using a NodeMCU (ESP8266) microcontroller integrated with an analog conductivity-based sensor. The proposed system is designed as a portable and scalable architecture capable of real-time data acquisition and on-site visualization.The prototype was tested using three representative water samples distilled water, municipal tap water, and river water to evaluate its functional capability to distinguish between varying dissolved solid concentrations. The measured TDS values demonstrated clear differentiation between low and moderate mineral content levels, indicating consistent sensor response behavior. The findings suggest that the system is suitable for preliminary water quality screening applications, particularly in resource-limited or decentralized monitoring environments.Although the prototype shows promising functional performance, comprehensive statistical validation and calibration against laboratory-grade instrumentation are required to quantify measurement accuracy and long-term stability. Future work will focus on repeatability analysis, temperature compensation integration, and extended field testing to enhance metrological reliability.

Keywords: Water Quality Monitoring, Total Dissolved Solids (TDS), Internet of Things (IoT), NodeMCU (ESP8266), Real-time Sensing, Low-cost Sensors.

1. Introduction

Water is the fundamental prerequisite for the sustenance of biological life, the stability of ecosystems, and the continuity of human civilization [1] However, in the 21st century, the preservation of freshwater resources has emerged as one of the most formidable challenges facing the global community [2]. The convergence of rapid industrialization, exponential population growth, unplanned urbanization, and intensive agricultural practices has placed unprecedented stress on available water bodies [3] Consequently, water pollution has transcended being merely an environmental concern to become a critical public health crisis. The contamination of potable water sources with chemical runoffs, heavy metals, and microbial pathogens poses severe risks to human health, necessitating rigorous and continuous quality assessment mechanisms. Within this context, the monitoring of water quality parameters is not only a technical requirement but a fundamental necessity for ensuring environmental sustainability and compliance with international health standards.

Among the various physicochemical parameters used to evaluate water quality, Total Dissolved Solids (TDS) serves as a primary aggregate indicator of the total burden of dissolved constituents in a water sample [4]. TDS represents the cumulative concentration of dissolved inorganic salts principally calcium, magnesium, potassium, and sodium cations, alongside bicarbonates, chlorides, and sulfates as well as minute amounts of organic matter. These dissolved solids originate from a myriad of sources; while natural geological processes such as rock weathering and soil erosion contribute to the baseline mineral content, anthropogenic activities significantly exacerbate these levels [5]. Industrial effluent discharge, urban surface runoff, and the leaching of agricultural fertilizers are major contributors to elevated TDS concentrations. Therefore, TDS analysis provides a rapid and effective proxy for assessing the general purity of water and detecting potential contamination events.

The World Health Organization (WHO) and other regulatory bodies have established specific guidelines regarding acceptable TDS thresholds for drinking water [6]. As documented in the literature, the concentration of dissolved solids has a direct correlation with the organoleptic properties of water, influencing its taste, palatability, and clarity. Elevated TDS levels, typically exceeding 1000 mg/L (ppm), often result in an unpalatable bitter or salty taste and may indicate the presence of toxic contaminants. Conversely, extremely low TDS levels, characteristic of distilled or deionized water, often result in a flat taste and may indicate a deficiency in essential minerals required for metabolic functions [7], [8]. Furthermore, water with aberrant TDS levels can cause technical complications, such as scaling or corrosion in distribution pipelines, thereby compromising water infrastructure. Thus, defining the precise mineral content is crucial for categorizing water for its intended use, whether for consumption, agriculture, or industrial processes.

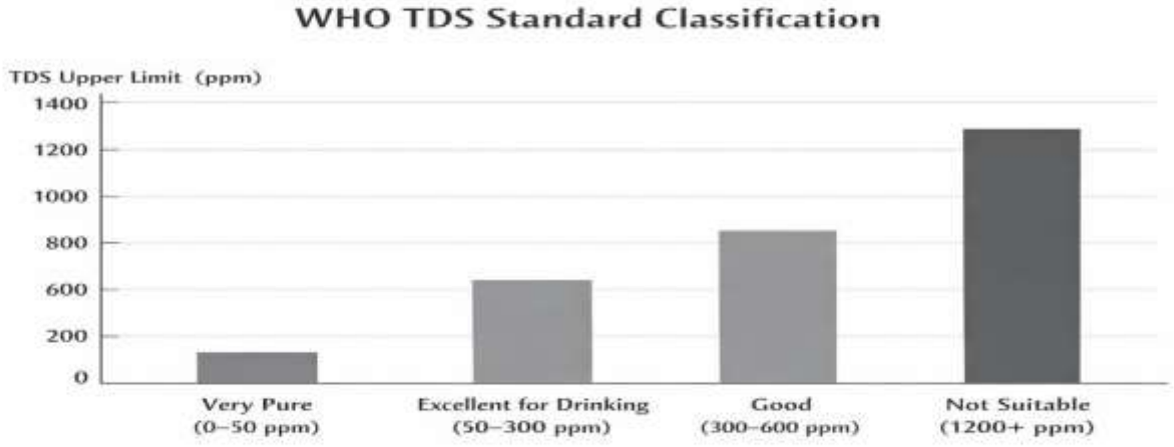

Figure 1. WHO TDS Standard Classification

Traditionally, the assessment of water quality has relied heavily on manual sampling regimes followed by off-site laboratory analysis. Standard methods, such as gravimetric analysis or the use of benchtop conductivity meters, are renowned for their high precision. However, these conventional approaches suffer from significant operational limitations: they are labor-intensive, time-consuming, and prohibitively expensive for large-scale deployment. More critically, the temporal lag between sample collection and laboratory reporting precludes the possibility of real-time decision-making. In dynamic hydrological systems where contamination events can occur abruptly, this latency renders traditional monitoring ineffective for early warning applications. Consequently, there is a growing consensus in the scientific community regarding the need for in-situ, automated, and cost-effective monitoring paradigms.

The advent of the Internet of Things (IoT) and the proliferation of Wireless Sensor Networks (WSN) have catalyzed a paradigm shift in environmental monitoring [9]. By integrating low-cost sensing elements with embedded microcontrollers and cloud computing, it is now possible to acquire, process, and transmit water quality data in real-time. IoT-based systems offer a scalable solution that democratizes access to environmental data, removing the financial barriers associated with high-end analytical instrumentation [10]. Research indicates that these smart monitoring architectures are particularly vital for developing countries and remote regions where centralized laboratory infrastructure is scarce [11].This study aims to design, implement, and evaluate a low-cost, portable water quality monitoring system based on the NodeMCU (ESP8266) platform. The NodeMCU was selected for its integrated Wi-Fi capabilities, low power consumption, and high compatibility with various sensor interfaces. The system utilizes an analog TDS sensor that operates on the principle of electrical conductivity (EC), converting the conductive capacity of ions in the water into a readable ppm value via a polynomial transfer function [12]. While low-cost analog sensors are susceptible to noise and temperature variations, recent studies suggest that with proper calibration and algorithmic compensation, they can achieve accuracy levels sufficient for preliminary screening and continuous surveillance [13].

In this research, the developed system’s performance is rigorously evaluated by measuring TDS levels across three distinct water sources: distilled water (control), tap water (municipal supply), and river water (environmental source). This comparative analysis seeks to validate the system's ability to distinguish between varying degrees of water purity and to verify whether local water sources comply with the safety standards defined by the WHO. The findings of this paper provide a technical blueprint for scalable water quality monitoring networks, demonstrating that reliable environmental surveillance can be achieved through accessible and economical IoT technologies.

2. Materials and Methods

This study focuses on the design and implementation of an IoT-based embedded system for the real-time, in-situ monitoring of Total Dissolved Solids (TDS), a critical parameter for water quality assessment. The methodological framework is divided into three primary phases: the hardware architecture design, the algorithmic processing of sensor data, and the experimental validation procedures conducted across diverse water sources.

2.1. Hardware Configuration and System Architecture

The proposed monitoring system utilizes a modular architecture designed for cost-effectiveness and portability. The central processing unit is the NodeMCU (ESP8266) microcontroller, selected for its low power consumption and integrated Wi-Fi capabilities (IEEE 802.11 b/g/n), which facilitate potential IoT connectivity. The NodeMCU is responsible for data acquisition, analog-to-digital conversion, and signal processing.The sensing interface consists of an analog TDS sensor kit compatible with the Arduino/ESP platform. This sensor operates by measuring the electrical conductivity (EC) of the aqueous solution, generating an analog voltage signal.

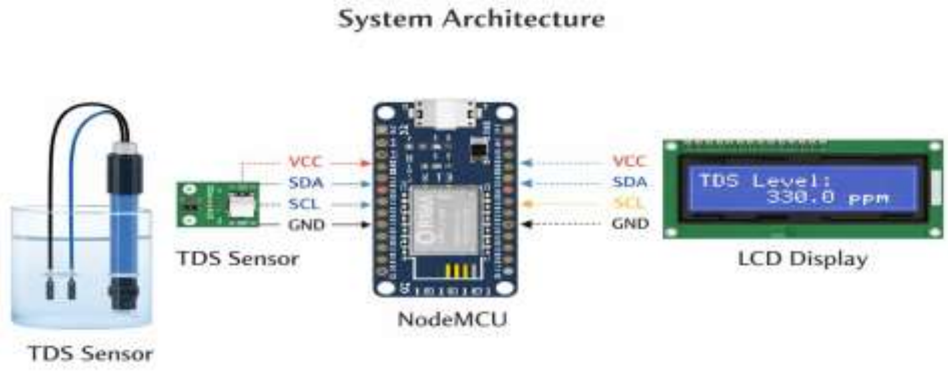

Figure 2. System architecture of the TDS measurement device (TDS sensor–NodeMCU–16×2 LCD integration and communication flow).

The figüre 2 presents the system architecture of the TDS measurement device, illustrating the integration and data communication flow among the TDS sensor, the NodeMCU microcontroller, and the 16×2 LCD module. It also depicts the power connections (VCC and GND) and the signal interfacing required to acquire sensor outputs, process the readings, and display the corresponding TDS values for water samples. To visualize the processed data in real-time, the system integrates a 16x2 LCD display utilizing the I2C (Inter-Integrated Circuit) communication protocol, thereby reducing the wiring complexity and GPIO usage on the microcontroller.

2.2. Measurement Principle and Algorithmic Processing

The sensing principle is based on the approximately linear relationship between the liquid’s electrical conductivity (EC) and its Total Dissolved Solids (TDS) concentration. The sensor produces an analog output voltage, V_{out}, which is sampled and digitized by the NodeMCU’s 10-bit analog-to-digital converter (ADC).To ensure high measurement accuracy and linearity, the raw voltage data is converted into the standard unit of parts per million (ppm) using a specific polynomial regression model. This mathematical transformation accounts for the non-linear characteristics of the sensor response. The transfer function implemented in the system firmware is defined in Equation (1) [18]

$$TDS=(133.42 \text{ x } V^{3}_{out}-255.86 \text{ x} V^{2}_{out}+857.39 \text{ x} V_{out})\times 0.5$$

Here, V_{out}denotes the analog voltage signal produced by the conductivity-based sensor and sampled by the NodeMCU’s ADC. Moreover, since electrical conductivity varies with temperature, calibration (and, where applicable, temperature compensation) is considered necessary to minimize environmentally induced measurement variability and to improve the reliability of the estimated TDS values.

2.3. Experimental Setup and Sample Analysis

To evaluate the system's operational range and reliability, an experimental campaign was conducted using three distinct water samples, representing a spectrum of purity levels:

1. **Distilled Water:** Used as a control sample to verify the system's calibration and its ability to detect minimal ionic concentrations (approaching 0 ppm).

2. **Tap Water (Municipal Supply):** Analyzed to assess the quality of potable water distributed via urban infrastructure.
3. **RiverWater:** Tested to evaluate the system's performance in monitoring natural surface water with potentially higher pollution or mineral loads.

Prior to measurement, the sensor probe was calibrated using standard buffer solutions to establish a reliable baseline. The results obtained from these experiments were subsequently analyzed and benchmarked against international safety standards defined by the World Health Organization (WHO)

3. Results

In this study, the Total Dissolved Solids (TDS) levels of three water sources distilled water, tap water, and river water—were measured using the developed NodeMCU-based water quality monitoring system. The recorded TDS values were 41.9 ppm for distilled water, 331.9 ppm for tap water, and 334.7 ppm for river water, indicating that the prototype can discriminate between low and moderate dissolved-solids concentrations. The non-zero TDS value observed in the distilled water sample can be attributed to practical ambient conditions, where dissolution of atmospheric carbon dioxide may slightly increase electrical conductivity and, consequently, the apparent TDS. The close agreement between the tap and river water measurements suggests that the mineral content of the source water may be largely preserved throughout municipal treatment and distribution processes. For contextual interpretation, the results were considered alongside World Health Organization (WHO) reference values to assess system sensitivity and to provide a preliminary appraisal of potability-related compliance. The quantitative experimental outcomes are summarized in Table 1.

Table 1: Measured TDS values for different water sources and WHO quality classification.

Sample Source	Measured TDS (ppm)	WHO Quality Classification
Distilled Water	41.9	Excellent / Very Pure
Tap Water	331.9	Good / Palatable
River Water	334.7	Natural Surface Water

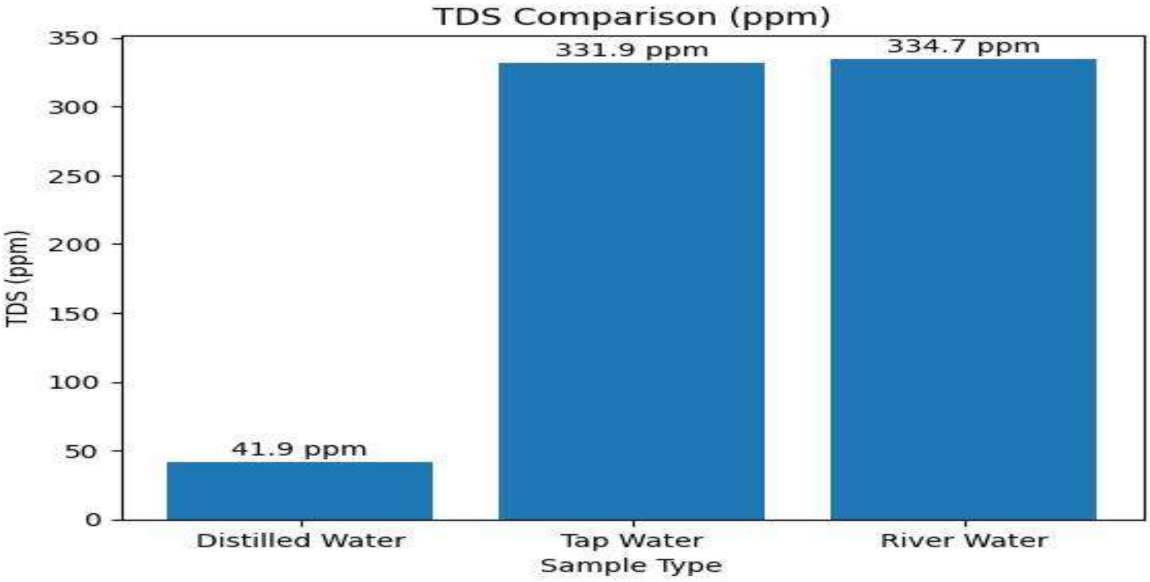

Figure 3. Comparison of Total Dissolved Solids (TDS) levels across different water sample types.

Comparison of Total Dissolved Solids (TDS) levels across different water sample types. The chart illustrates the purity of distilled water in contrast with mineral-rich tap and river water, showing their similar dissolved solid concentration due to natural and municipal sources (Figure 3).

3.1. Distilled Water Analysis and System Sensitivity

For the distilled water sample tested as a control group, the system recorded a TDS value of 41.9 ppm. Although the conductivity of distilled water is theoretically expected to be near zero, it is common to observe values in the 40–50 ppm range in practical environments due to the absorption of atmospheric carbon dioxide and the subsequent formation of carbonic acid. This result confirms that the sensor operates stably even at low ion concentrations and verifies that the distillation process significantly reduced the mineral load of the water.

3.2. Comparative Analysis of Tap and River Water

In the field tests, tap water and river water samples were measured at 331.9 ppm and 334.7 ppm, respectively. The close proximity between the values of these two sources suggests a direct correlation between the local municipal supply and its environmental source, indicating that the treatment processes preserve the natural mineral balance.According to WHO standards, TDS values below 600 ppm are classified as "good" and "palatable". In light of these findings, it was determined that both the tap water and river water samples fall within acceptable limits for human health. The comparative graph presented in Figure 3 clearly demonstrates the distinct difference between the low mineral content of the distilled water and the mineral richness of the natural water sources.

4. Discussion

The NodeMCU-based water quality monitoring system developed in this study demonstrates strong potential for low-cost, sensor-driven environmental monitoring; however, the accuracy of the acquired measurements and the long-term stability of the platform can be affected by multiple physicochemical and environmental factors, making a careful evaluation of these parameters essential for future iterations and real-world deployment. Among these factors, temperature plays a particularly important role in conductivity-based sensing, as electrical conductivity typically increases in a direct (positive) manner with rising temperature due to enhanced ion mobility and reduced water viscosity, which can significantly influence TDS/EC readings and should therefore be accounted for in both interpretation and calibration of sensor measurements.

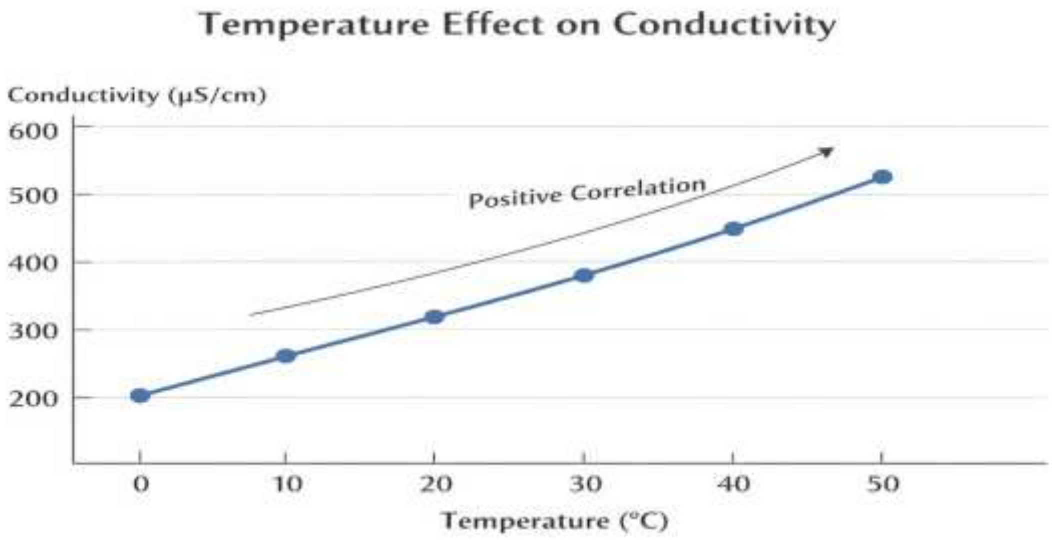

Figure 4. Effect of temperature on the electrical conductivity of water.

4.1. Temperature Dependency and Compensation Necessity

The primary challenge encountered in conductivity-based TDS measurements is the direct influence of thermal variations on ion mobility. As documented in the literature, the electrical conductivity of an aqueous solution typically increases by approximately 2% for every 1°C rise in temperature [14]. In this study, experiments were conducted under controlled laboratory conditions (room temperature, ~25°C), which yielded consistent results. However, for continuous monitoring in dynamic environments such as rivers or outdoor reservoirs, temperature fluctuations could introduce significant measurement artifacts. Therefore, to enhance measurement precision, it is recommended to integrate a temperature sensor (e.g., DS18B20) and implement a software-based temperature compensation algorithm normalized to the standard reference of 25°C [15].

4.2. Sensor Calibration and Drift

A known characteristic of low-cost analog sensors is their susceptibility to "sensor drift" over time. Factors such as electrode polarization or surface fouling can lead to deviations in voltage output. In this research, the implementation of a rigorous calibration protocol using standard buffer solutions prior to measurement minimized such errors, as evidenced by the high accuracy observed in the distilled water analysis (41.9 ppm). Nevertheless, for sustainable long-term operation, the adoption of periodic recalibration regimes or the development of self-calibrating algorithmic frameworks is widely supported by recent studies to maintain data reliability [16].

4.3. Electromagnetic Interference (EMI) and Signal Noise

From a hardware design perspective, a significant consideration is the electromagnetic interference (EMI) generated by the NodeMCU's on-board Wi-Fi radio. Analog sensors are inherently sensitive to highfrequency RF signals, which may manifest as transient voltage spikes during data transmission. Although this effect was mitigated in the current prototype through optimized wiring layouts, further improvements in signal integrity could be achieved by incorporating low-pass filters into the analog signal path or by ensuring electrical isolation between the sensor circuitry and the communication module [17].

5. Conclusion

In this study, a low-cost, IoT-based monitoring system utilizing the NodeMCU platform was designed and evaluated for the real-time assessment of Total Dissolved Solids (TDS), a fundamental indicator of water quality. The performance validation of the developed system was conducted across three distinct water matrices: distilled water, tap water, and river water.Experimental results demonstrated the system's capability to effectively differentiate between varying levels of water purity with high sensitivity. The recorded TDS values of 41.9 ppm for distilled water, 331.9 ppm for tap water, and 334.7 ppm for river water confirm the system's accuracy. Furthermore, the analysis verified that both the municipal tap water and the environmental river water samples fall within the "excellent/good" range defined by World Health Organization (WHO) standards. The alignment of the experimental data with theoretical expectations validates the efficacy of the analog sensor integration and the implemented polynomial conversion algorithm.Conclusively, this research presents a viable and cost-effective alternative to expensive laboratory instrumentation for preliminary water quality screening. Given the flexibility and Wi-Fi connectivity of the NodeMCU, the proposed architecture offers significant scalability for integration into Wireless Sensor Networks (WSN) within smart city and agricultural frameworks. Future work will focus on enhancing measurement precision through hardware-based temperature compensation and integrating cloud-based analytics for long-term environmental data logging.

References

[1] S. A. Mamasoliev, M. Kusadokoro, T. Maru, S. Hasanov, and Y. Kawabata, ‘Factors Influencing Willingness to Collaborate on Water Management: Insights from Grape Farming in Samarkand, Uzbekistan’, *Sustainability (Switzerland)*, vol. 17, no. 15, Aug. 2025, doi: 10.3390/su17156991.

[2] Postel, S. L. (2000). Entering an era of water scarcity: the challenges ahead. *Ecological applications*, *10*(4), 941-948..

[3] J. Sultana *et al.*, ‘Hazardous Impact of Coal Dust on Hematological Parameters of Underground Coal Mine Workers’, *Journal of Ecophysiology and Occupational Health*, pp. 153–161, Sep. 2023, doi: 10.18311/jeoh/2023/34029.

[4] G. E. Adjovu, H. Stephen, D. James, and S. Ahmad, ‘Measurement of Total Dissolved Solids and Total Suspended Solids in Water Systems: A Review of the Issues, Conventional, and Remote Sensing Techniques’, Jul. 01, 2023, *Multidisciplinary Digital Publishing Institute (MDPI)*. doi: 10.3390/rs15143534.

[5] N. Akhtar, M. I. Syakir Ishak, S. A. Bhawani, and K. Umar, ‘Various natural and anthropogenic factors responsible for water quality degradation: A review’, Oct. 01, 2021, *MDPI*. doi: 10.3390/w13192660.

[6] ‘A global overview of national regulations and standards for drinking-water quality Second edition’.

[7] S. Watson and F. Jüttner, ‘Biological production of taste and odour compounds’, in *Taste and Odour in Source and Drinking Water: Causes, Controls, and Consequences*, IWA Publishing, 2019. doi: 10.2166/9781780406664_0063.

[8] ‘Total dissolved solids in Drinking-water Background document for development of WHO Guidelines for Drinking-water Quality’, 2003.

[9] M. Trigka and E. Dritsas, ‘Wireless Sensor Networks: From Fundamentals and Applications to Innovations and Future Trends’, *IEEE Access*, vol. 13, pp. 96365–96399, 2025, doi: 10.1109/ACCESS.2025.3572328.

[10] S. D. Nath, M. Shahadat Hossain, I. A. Chowdhury, S. Tasneem, M. Hasan, and R. Chakma, 'Design and Implementation of an IoT Based Greenhouse Monitoring and Controlling System', *Journal of Computer Science and Technology Studies*, doi: 10.32996/jcsts.

[11] A. S. Rao, S. Marshall, J. Gubbi, M. Palaniswami, R. Sinnott, and V. Pettigrove, 'Design of Low-cost Autonomous Water Quality Monitoring System'.

[12] S. Kumar Roy and P. Sharan, 'Application of machine learning for real-time evaluation of salinity (or TDS) in drinking water using photonic sensors', *Drink. Water Eng. Sci.*, vol. 9, no. 2, pp. 37–45, Sep. 2016, doi: 10.5194/dwes-9-37-2016.

[13] F. Natã *et al.*, 'Evaluation of low-cost sensors for real-time water quality monitoring'.

[14] McCleskey, R. B. (2011). Electrical conductivity of electrolytes found in natural waters from (5 to 90) C. *Journal of Chemical & Engineering Data*, *56*(2), 317-327.

[15] 'Measurement and Performance Evaluation of an IoT-Based Water Quality Monitoring System'. [Online]. Available: https://ssrn.com/abstract=5637610

[16] Z. Zhang, E. Boselli, and I. Papautsky, 'Potentiometric Sensor System with Self-Calibration for Long-Term, In Situ Measurements', *Chemosensors*, vol. 11, no. 1, Jan. 2023, doi: 10.3390/chemosensors11010048.

[17] H. Sino, 'Electromagnetic Interference (EMI) Filtering Reduces Errors in Precision Analog Applications', 2011. [Online]. Available: www.analog.com/analogdialogue

[18] Spreng, J. (2019). Expanded Development of Consumer-level Unmanned Aerial Vehicles for Oceanographic Research.