VFAST Transactions on Software Engineering
https://vfast.org/journals/index.php/VTSE@ 2025, ISSN(e): 2309-3978, ISSN(p): 2411-6246
Volume 13, Number 1, January-March 2025 pp: 207-216

Smart Water Quality Management System: A Case Study of Tharparkar Region

Zain ul Abdin Shaikh [1], **Umair Ahmed Korai** [2*], **Faisal Karim Shaikh** [2], **Saeed Ahmed Talpur** [3]

[1]Institute of Information and Communication Technologies, Mehran University of Engineering & Technology, 76062, Jamshoro, Pakistan; [2]Department of Telecommunication Engineering, Mehran University of Engineering & Technology, Jamshoro, 76062, Pakistan; [3]Information Technology Centre, Sindh Agriculture University Tandojam, 70060, Pakistan

Keywords: *Sensors, water quality, Internet of things, Machine Learning, real-time monitoring.*

Journal Info:
Submitted: February 27, 2025
Accepted: March 20, 2025
Published: March 31, 2025

Abstract

In this paper, we present the design and implementation of a smart water quality monitoring system for the Tharparkar region of Pakistan, where access to clean water is limited. The system utilizes Internet of Things (IoT) sensors and machine learning algorithms to assess and predict water quality. Parameters such as pH, turbidity, and total dissolved solids were continuously monitored using IoT sensors deployed in three strategically selected groundwater wells in Tharparkar. The collected data was transmitted wirelessly to a central server, where a Support Vector Regression model was applied to analyze water quality trends and classify samples as polluted or unpolluted. The results demonstrate the system's effectiveness in providing accurate, timely, and location-specific information, enabling early detection of contamination, and supporting proactive water resource management. This work highlights the potential of integrating IoT and artificial intelligence to address water scarcity and quality challenges in an underdeveloped region.

***Correspondence author email address:** umair.korai@faculty.muet.edu.pk
DOI: 110.21015/vtse.v13i1.2084

1 Introduction

Water is one of the essential resources for people and is important for farming, manufacturing, drinking, and sustaining life on Earth. Many countries, including Pakistan, face a shortage of freshwater. The main reasons for this shortage are the effects of climate change and the lack of periodic monitoring and testing of water quality [1]. This critical situation motivates countries to use the available freshwater resources more effectively. Freshwater can be obtained mainly from groundwater, rain, and rivers [2].

However, water quality is severely deteriorated by pollution and sewage depositions. Recently, it was found that the Water and Sanitation Agency (WASA), Hyderabad, Pakistan, has stopped lifting water from the Indus River due to a constant increase in the levels of Total Dissolved Solids (TDS) [3].

Previously, water quality was manually monitored. For example, samples of water from different wells or the sea were brought to laboratories, where manual tests were conducted. Most of these processes required extensive laboratory facilities equipped with expensive equipment, as well as significant human effort and time, but did not provide real-time data [4], [5].

Taking into account these challenges, researchers are motivated to adopt Internet of Things (IoT) technology for effective monitoring of water quality [6–8]. The term IoT refers to the concept of connecting sensors, machines, software, and objects to the Internet. Researchers have developed different IoT-based solutions for monitoring water quality [9–11]. Many of these systems successfully provide information related to water status and detect pollutants before they become uncontrollable. Sensors capable of monitoring parameters like pH, TDS, turbidity, and others are readily available and can be used in real-time systems for water quality monitoring. This real-time information facilitates the immediate detection of any deviation or abnormality from the desired water quality standards, allowing prompt action to resolve the problem. Artificial intelligence (AI) enhances these systems by enabling advanced processing, such as the analysis and interpretation of sensor data [12–14].

Consequently, the AI models developed can predict issues related to water quality and provide early warnings accordingly. The installation of smart water quality systems adopting IoT and AI technologies is a major step in managing water resources. The shift from reacting to problems to preventing them helps ensure safe and sustainable water for various purposes.

Tharparkar is one of the rural areas of Pakistan where necessities such as clean water, quality education, healthcare, electricity, and telecommunication services are rarely available [15]. The region has a semi-arid climate, which results in rare rainfall and leads to a shortage of freshwater. It is considered one of the most water-deficient regions of Pakistan, where groundwater is the only major source of freshwater. Additionally, a study shows that 87% of the water samples collected were unsafe for drinking, with all samples deemed completely unsuitable for infants [16]. This makes real-time water quality monitoring critically important for the region.

Water quality monitoring has been a focus of research for decades, especially with the advent of IoT technologies and artificial intelligence (AI) for data analysis and prediction [17–19]. Several studies have explored various frameworks for water quality assessment and management. For instance, [2] developed an IoT-based system for real-time water quality monitoring using a network of sensors, which enabled the measurement of parameters such as pH, turbidity, and dissolved oxygen. This system, while effective in urban settings, faced challenges in deployment in rural areas due to a lack of infrastructure and varying climatic conditions. Similarly, [12] implemented a machine learning approach to predict water quality parameters based on historical data. Their model demonstrated promising accuracy; however, it relied on laboratory results rather than real-time measurements, limiting its applicability in dynamic environments. Furthermore, the study did not address specific regional challenges that influence water quality, such as seasonal variations and local human activities. In contrast, the present research addresses these gaps by presenting the first comprehensive study of live data for water quality monitoring in the Tharparkar region, utilizing data collected over six months. Prior studies have largely overlooked this area, and the continuous data collection approach allows for a more nuanced understanding of water quality fluctuations.

In this work, we deployed sensors (such as TDS, pH, turbidity, and temperature sensors) at different locations of groundwater wells in Tharparkar, Pakistan. The data collected from the sensors is transmitted wirelessly and stored on a central cloud/server. An AI model is then applied to the stored data, which is responsible for predicting future water quality.

The reminder of the paper is set as: Section II describes the IoT system models, and the details of sensors used for the collection of real-time water samples;

Section III represents the design and experimental results and applying AI models for prediction. Section IV corresponds to the results and discussions followed by the conclusion in section V.

2 Literature Review

The Tharparkar region of Pakistan is characterized by its arid climate, limited water resources, and a predominantly rural population that relies heavily on groundwater for drinking. Several studies have assessed the water quality in Tharparkar, focusing on parameters such as pH, Total Dissolved Solids (TDS), turbidity, and microbiological contamination. For instance, a study by [20] found that groundwater in Tharparkar often exhibits high TDS levels, exceeding the acceptable limits for drinking water set by the World Health Organization (WHO). High TDS levels are often attributed to the geological composition of the region, which includes saline deposits. Additionally, the pH levels in many wells were found to be outside the recommended range, contributing to concerns about water safety and palatability. The health implications of poor water quality in Tharparkar have been documented in various studies.

IoT-based water quality monitoring has gained significant attention due to its real-time capabilities and automation advantages. Recent applications include laboratory-scale moving bed biofilm reactors (MBBRs), where IoT sensors monitor critical parameters like pH, temperature, and total dissolved solids (TDS) to optimize biofilm performance [21]. For rural areas, researchers developed a portable, solar-powered LoRaWAN-based IoT system that measures pH, turbidity, TDS, and temperature, offering a waterproof and energy-efficient solution [22]. Further advancements integrate machine learning for enhanced analysis; one study employed an Arduino and NB-IoT system to collect real-time data (e.g., temperature, pH, and contaminants) and used classifiers—including Decision Trees (DT), Gradient Boosting (GB), and Neural Networks (NN)—to assess potability, complemented by SMS alerts for remote monitoring [23]. Another framework leverages machine learning (e.g., AdaBoost, random forest) based IoT-Wireless Sensor Networks (WSN) to predict unsensed parameters like E. coli concentrations [24]. This study developed an IoT-based water quality monitoring system for Asian seabass aquaculture, enhancing low-cost sensor accuracy (76–97%) through simple linear regression validated against YSI Professional Pro [25].

A survey conducted by [26] revealed a strong correlation between water quality and the prevalence of waterborne diseases, such as cholera and dysentery, particularly among children. The study highlighted that communities relying on contaminated water sources faced higher health risks, emphasizing the urgent need for improved water quality management. Furthermore, research by [27] indicated that the lack of access to safe drinking water exacerbates malnutrition and other health issues, particularly in vulnerable populations. Despite the recognition of water quality issues, effective management remains a challenge in Tharparkar. The authors emphasized the need for a multi-stakeholder approach involving local communities, government agencies, and non-governmental organizations (NGOs) to develop sustainable solutions.

While existing studies provide valuable insights into the water quality challenges in Tharparkar, significant research gaps persist. Most studies have focused on specific water quality parameters without considering the cumulative effects of multiple contaminants. There is a lack of comprehensive studies that examine the long-term impacts of poor water quality on public health and socio-economic development in the region. Furthermore, limited research has been conducted on the effectiveness of existing water quality management practices and policies, indicating a need for their evaluation and adaptation to local conditions. These innovations highlight IoT's transformative potential, though challenges in standardization and industry adoption persist.

3 IoT System Model

In the proposed smart water quality management system, we employed a wide range of sensors to monitor the essential indicators of water quality. The system was fitted with:

- DFRobot PH Meter (SKU: DFR0341) with a range of 0 to 14 pH and accuracy of ±0.1 pH.
- DFRobot TDS Meter (SKU: DFR0342) with a range of 0 to 1000 ppm and accuracy of ±10% FS.
- DFRobot Turbidity Sensor (SKU: DFR0318) with a range of 0 to 1000 NTU and accuracy of ±10% FS.
- DS18B20 Temperature Sensor with a range of -55°C to +125°C and accuracy of ±0.5°C.

These sensors are responsible for collecting real-time data from three different wells in Tharparkar. The microcontroller ESP32 was used for data collection and transmission from the sensors to the central monitoring system. This versatile microcontroller has many capabilities, such as Wi-Fi, Bluetooth, and low power consumption, making it an ideal choice for our smart water quality system [6]. We used the real-time water quality data transmitted to our central monitoring system and analyzed it using machine learning algorithms. Our research proved effective in monitoring and predicting water quality through a smart water quality management system.

The block diagram in Fig. 1 illustrates the system layout, which features an interface where three sensors are connected to a microcontroller to measure pH, turbidity, and total dissolved solids in the water samples. The signal that the pH sensor sends reflects the logarithmic value of acidity or alkalinity. The turbidity sensor functions by detecting suspended particles through light scattering. The ESP32 microcontroller gathers data from the on-site sensors and sends it to ThingSpeak over the Internet. Using a machine learning algorithm, the sensor data serves as the basis for predicting water quality in the backend. Support Vector Regression (SVR) is selected as the best regression model to predict water quality and categorize samples as either “unpolluted” or “polluted.” More precise measurements of water quality in wells were achieved by collecting water samples monthly from three wells, and after their analysis, the prediction results were evaluated.

4 Design and Experiment

4.1 Prototype Design

A prototype device has been developed to make the smart water quality management system more efficient and versatile. This device integrates all its components into a compact and user-friendly design, including sensors for pH, turbidity, and total dissolved solids, as well as an ESP32 microcontroller and data communication and collection circuits. The prototype model offers high convenience and is generally easy to install, making it suitable for broad use in diverse water management systems and facilities.

4.2 Circuit Diagram

Figure 3 presents the circuit diagram of the sensors (pH, turbidity, and total dissolved solids) and the ESP32 microcontroller. Each of these sensors relates to red, black, and the constant error correction data through the 5V power supply wire, grounding, and wire introduce the data respectively.

4.3 Methodology

In this study, we employed a multi-phase methodology to monitor and predict the water quality in three wells located at different locations of Tharparkar district. The data was monitoring using IoT sensors and the data was predicted using the Support Vector Regression (SVR) models. Following steps were taken during this whole process:

4.3.1 Real-time data collection

Real-time sensor data were collected from three groundwater wells from July to December 2023. Sensors recorded key water quality parameters, including pH, total dissolved solids (TDS), and turbidity. These parameters are critical indicators of water potability and environmental health.

4.3.2 Data Preprocessing

The collected data were cleaned and normalized to ensure consistency and accuracy. Outliers and missing values were addressed to prepare the dataset for model training. Time-series formatting was applied to align the data with temporal patterns.

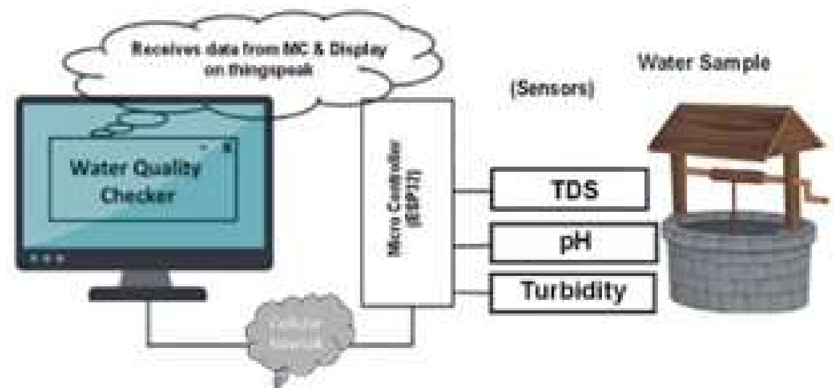

Figure 1. Block diagram of the system summary

Figure 2. Exterior casing and sensors.

4.3.3 Data Analysis

The collected data was analyzed in form of descriptive statistics and visualization to understand the distribution and range of the parameters for each well, explained in later section.

4.3.4 Model Development: Support Vector Regression (SVR)

SVR model was used to predict the water quality parameters based on collected real-time IoT sensor data. SVR was selected due to its high accuracy in handling nonlinear relationships and continuous outputs. The models were trained and validated using real-time datasets to evaluate their predictive capabilities.

4.3.5 Model Evaluation and Comparison

The predictions from the SVR models were compared with actual sensor readings. A close match between predicted and observed values demonstrated the models' reliability for real-time water quality forecasting, especially in identifying safe versus unsafe water conditions.

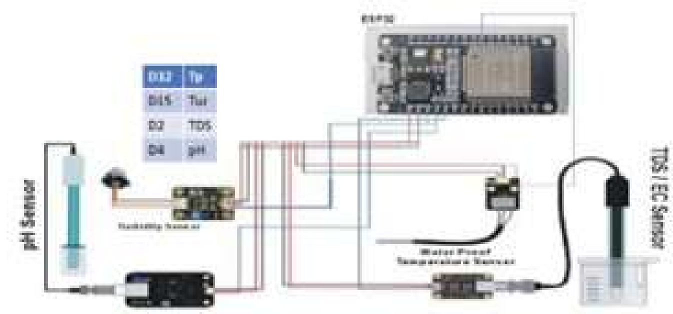

Figure 3. Circuit diagram of the hardware.

5 Results and Discussion

Real-time data was gathered from the sensors installed in three wells in the Tharparkar district from July to December 2023. The sensor dataset encompassed measurements such as pH, TDS, and turbidity, allowing for in-depth supervision and examination of the water quality of the wells. The water quality data obtained from the sensors served to enrich the SVR models, which were built specifically to predict water quality. The comparison showed a close match provided by the SVR algorithm when real-time data samples were processed. This indicated that the water quality parameters could be accurately forecasted based on the real-time data collected. This high level of prediction accuracy demonstrates that the SVR models are reliable tools for monitoring water quality in real-time, ensuring timely interventions and maintaining safe water standards in the Tharparkar district. To further enhance prediction accuracy, incorporating additional data points such as temperature, rainfall patterns, and groundwater flow rates could be beneficial. These factors can significantly influence water quality, and their inclusion would provide a more comprehensive understanding of the environmental conditions affecting the wells. Additionally, integrating historical data on seasonal variations could help refine the models' predictive capabilities.

5.1 Well 1

The results shown in Fig. 4 indicate that the water in Well 1 had a pH level within the acceptable range for drinking water (6.5–8.5), with an average value of 7. In Well 1, the total dissolved solids ranged from 400 to 500 ppm, indicating good water quality. The turbidity level in Well 1 was consistently below 3 NTU (nephelometric turbidity units), suggesting that the water was clean and free of visible particles or contaminants. These findings suggest that the water in Well 1 is acceptable for drinking, and no immediate action is required to improve its quality. Furthermore, users reported the water's taste and odor as satisfactory, reinforcing its acceptability. Continued monitoring should maintain these standards and promptly address any potential issues. A regular testing schedule and quick response to any concerns are crucial for maintaining water safety.

5.2 Well 2

However, Fig. 5 indicates that surprising elements that were detected from Well 2. The pH level remained a constant overshot with a mean deviation of 7.5. This implies alkaline water, and it may cause health problems, as well as the water becoming bitter. Besides abounding more than 400 ppm in the total soluble solids in Well 2, which frequently occurred, contributed to the unpleasant taste and unsafe drinking water. The turbidity value fluctuates between 2.5 and 3 NTU units, marking some cloudiness which shows that the water body has a lot of sediments in it. These findings highlight the low quality of water in Well 2 and the need for action to enhance its acceptability for drinking. Based on the analysis of Fig. 4 and Fig. 5, it is appropriate to employ regression rather than classification for the machine learning task, as the dataset comprises continuous readings rather than discrete labels. This methodology facilitates a more comprehensive understanding of the relationships between variables such as pH levels, total dissolved solids, turbidity, and temperature. Utilizing regression allows for clearer insights into water quality, particularly in comparing the conditions of Well 1 and Well 2. This approach will enhance our understanding of the suitability of drinking water and identify potential areas for improvement.

5.3 Well 3

In Fig. 6, Well 3 also showed negative water quality values, further indicating a disturbed environment. The pH level was not only persistent but also low, with a mean value of 8, indicating the acidity of the water. The turbidity readings ranged from 5.5 to 6 NTU, implying that massive amounts of cloudiness and debris are present. Furthermore, the total dissolved solids were consistently above 900 ppm in all samples, revealing high salinity and mineral habitation. Moreover, these results show that the water quality is very low in Well 3; therefore, it cannot be considered safe for consumption or drinking purposes, hence the urgent need for intervention. The high levels of salinity and minerals, coupled with the low pH and high turbidity, indicate that the water in Well 3 is not only unsafe for consumption but also poses a significant risk to the environment. Immediate intervention is necessary to address these issues and restore water quality to safe levels.

Table 1. A comprehensive analysis and interpretation of all wells in Tharparkar

Well #	pH	TDS	Turbidity	Safe
1	7	400-500	2.5-3	Safe
2	7.5	400-450	2.5-3	Safe
3	8	900-950	5.5-6	Not safe

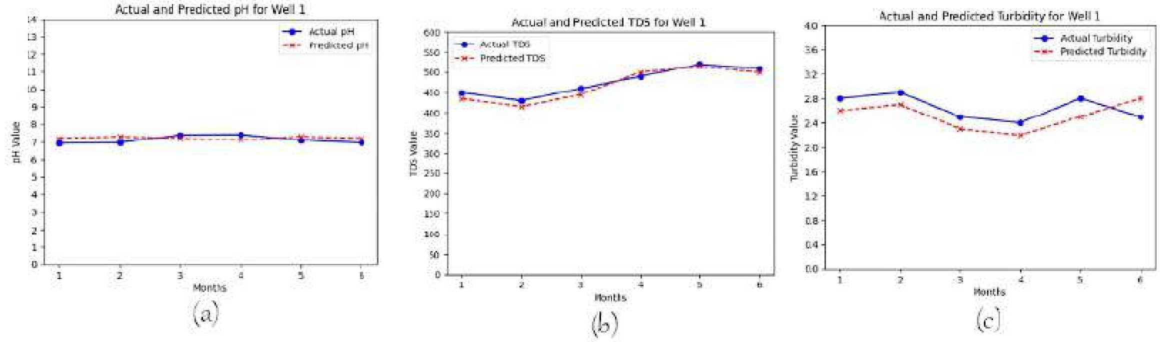

Figure 4. Real-time and predicted data of well 1. (a) pH (b) TDS (c) Turbidity for six months.

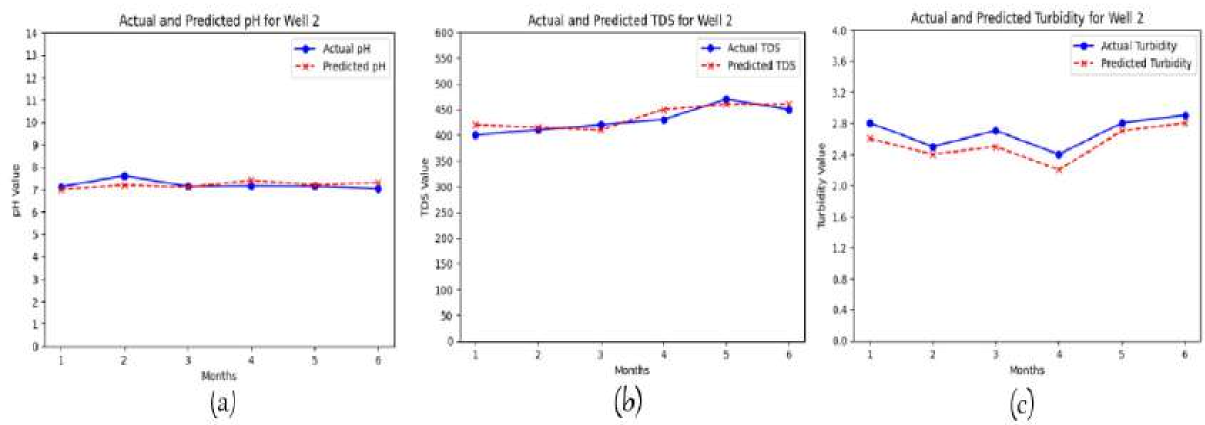

Figure 5. Real-time & predicted data of well 2. (a) pH (b) TDS (c) turbidity for 6 months.

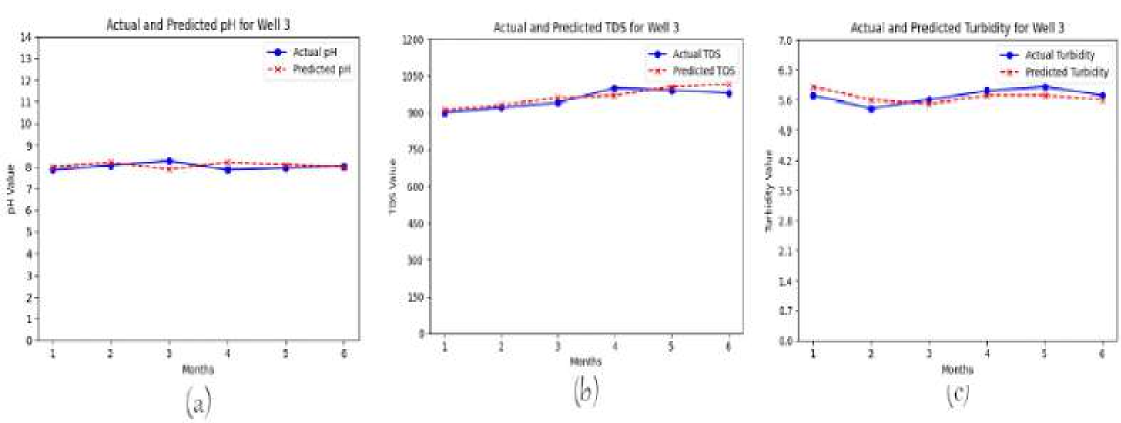

Figure 6. Real-time and predicted data of well 3. (a) pH (b) TDS (c) Turbidity for six months.

6 Conclusion

The data from the three wells provide insights into water quality and potential usability for drinking and other purposes. The pH values range from 7 to 8, indicating that the water is mostly neutral to slightly alkaline, which is generally acceptable for drinking, helping prevent plumbing corrosion and preserving essential minerals. TDS levels are crucial in assessing water quality: Wells 1 and 2 have TDS levels below 500 ppm, considered safe for drinking, whereas Well 3 shows significantly higher values (900–950 ppm), suggesting a high concentration of dissolved minerals or potential contaminants. High TDS can affect taste and indicate poorer water quality, making it less suitable for consumption without treatment. Turbidity levels in Wells 1 and 2 are low, indicating clear water with minimal suspended particles. Conversely, Well 3's turbidity level of 6.5 NTU suggests the presence of suspended solids that could harbor pathogens or pollutants, raising safety concerns. Overall, while Wells 1 and 2 provide safe and clear water, Well 3 requires further investigation and treatment before being deemed safe for drinking. Using Support Vector Regression models, we implemented predictive models based on the collected data to forecast future water quality and alert for potential contamination months in advance. Finally, the device's performance was enhanced by incorporating pH, turbidity, and TDS sensors in a compact, user-friendly design. User feedback complemented technical assessments by identifying issues like taste or odor changes, ensuring that the water remains both safe and satisfactory for consumption.

Author's Contribution

Zain ul Abdin Shaikh contributed to the system design and prototype development. **Umair Ahmed Korai** supervised the project and guided the implementation of AI models. **Faisal Karim Shaikh** assisted in data analysis and result validation. **Saeed Ahmed** contributed to literature review and manuscript editing.

Compliance with Ethical Standards

It is declare that all authors do not have any conflict of interest. It is also declared that this article does not contain any studies with human participants or animals performed by any of the authors. Furthermore, informed consent was obtained from all individual participants included in the study.

Funding Information

We truly are thankful to EPICS in IEEE for their generous financing and assistance, which has been critical to the successful deployment of our smart water quality monitoring system in the Tharparkar region. The work has been crucial in resolving the major problems associated with water quality in the area.

References

[1] M. Tariq, N. van de Giesen, S. Janjua, M. Shahid, and R. Farooq, "An Engineering Perspective of Water Sharing Issues in Pakistan," *Water (Basel)*, vol. 12, no. 2, p. 477, Feb. 2020, doi: 10.3390/w12020477.

[2] F. Jan, N. Min-Allah, and D. Düştegör, "IoT Based Smart Water Quality Monitoring: Recent Techniques, Trends and Challenges for Domestic Applications," *Water*, vol. 13, no. 13, p. 1729, Jun. 2021, doi: 10.3390/W13131729.

[3] "Wasa stops lifting water from Indus, off-taking canals - Newspaper - DAWN.COM." Accessed: Jan. 05, 2025. [Online]. Available: https://www.dawn.com/news/1825301/wasa-stops-lifting-water-from-indus-off-taking-canals

[4] R. Yue and T. Ying, "A water quality monitoring system based on wireless sensor network & solar power supply," in *Proc. IEEE Int. Conf. Cyber Technology in Automation, Control, and Intelligent Systems*, Mar. 2011, pp. 126–129, doi: 10.1109/CYBER.2011.6011777.

[5] F. Meng, G. Fu, and D. Butler, "Cost-Effective River Water Quality Management using Integrated Real-Time Control Technology," *Environ. Sci. Technol.*, vol. 51, no. 17, pp. 9876–9886, Sep. 2017, doi: 10.1021/acs.est.7b01727.

[6] A. D. B. Jáquez, M. T. A. Herrera, A. E. M. Celestino, E. N. Ramírez, and D. A. M. Cruz, "Extension of LoRa Coverage and Integration of an Unsupervised Anomaly Detection Algorithm in an IoT Water Quality Monitoring System," *Water (Switzerland)*, vol. 15, no. 7, p. 1351, Apr. 2023, doi: 10.3390/W15071351/S1.

[7] E. T. de Camargo, A. N. de Souza, R. S. Vieira, R. N. Cardoso, and F. A. S. Ferrari, "Low-Cost Water Quality Sensors for IoT: A Systematic Review," *Sensors*, vol. 23, no. 9, p. 4424, Apr. 2023, doi: 10.3390/S23094424.

[8] C. Z. Zulkifli, M. A. Abdul Majeed, A. B. S. Ali, M. A. Ramli, M. A. M. Ali, and R. Z. Abidin, "IoT-Based Water Monitoring Systems: A Systematic Review," *Water*, vol. 14, no. 22, p. 3621, Nov. 2022, doi: 10.3390/W14223621.

[9] U. Ahmed, R. Mumtaz, H. Anwar, S. Mumtaz, and A. M. Qamar, "Water quality monitoring: from conventional to emerging technologies," *Water Supply*, vol. 20, no. 1, pp. 28–45, Feb. 2020, doi: 10.2166/ws.2019.144.

[10] C. Z. Zulkifli, M. A. Abdul Majeed, A. B. S. Ali, M. A. Ramli, M. A. M. Ali, and R. Z. Abidin, "IoT-Based Water Monitoring Systems: A Systematic Review," *Water (Basel)*, vol. 14, no. 22, p. 3621, Nov. 2022, doi: 10.3390/w14223621.

[11] R. K. Nishan, S. Akter, R. I. Sony, et al., "Development of an IoT-based multi-level system for real-time water quality monitoring in industrial wastewater," *Discover Water*, vol. 4, p. 43, 2024, doi: 10.1007/s43832-024-00092-y.

[12] M. Hmoud Al-Adhaileh and F. Waselallah Alsaade, "Modelling and Prediction of Water Quality by Using Artificial Intelligence," *Sustainability*, vol. 13, no. 8, p. 4259, Apr. 2021, doi: 10.3390/su13084259.

[13] S. N. Zainurin, M. F. A. Malek, N. A. M. Ali, S. Abdullah, and N. H. H. Khalid, "Advancements in Monitoring Water Quality Based on Various Sensing Methods: A Systematic Review," *Int. J. Environ. Res. Public Health*, vol. 19, no. 21, p. 14080, Oct. 2022, doi: 10.3390/ijerph192114080.

[14] R. K. Nishan, S. Akter, R. I. Sony, et al., "Development of an IoT-based multi-level system for real-time water quality monitoring in industrial wastewater," *Discover Water*, vol. 4, p. 43, 2024, doi: 10.1007/s43832-024-00092-y.

[15] R. Khalid, S. Landini, G. Das Valasai, F. Khalid, and P. Sandwell, "Towards equitable and inclusive energy systems for remote off-grid communities: A socio-technical assessment of solar power for village Helario in Tharparkar, Pakistan," *Renew. Sustain. Energy Trans.*, vol. 4, p. 100067, Aug. 2023, doi: 10.1016/J.RSET.2023.100067.

[16] T. Begum, A. Shareef, T. Rafique, and H. A. Khwaja, "Assessment of groundwater quality with special emphasis on fluoride contamination: a case study in Thar Desert, Pakistan," *Sustain. Water Resour. Manag.*, vol. 10, no. 2, p. 53, Apr. 2024, doi: 10.1007/s40899-023-01024-9.

[17] M. A. Murti, A. R. A. Saputra, I. Alinursafa, et al., "Smart system for water quality monitoring utilizing long-range-based Internet of Things," *Applied Water Science*, vol. 14, p. 69, 2024, doi: 10.1007/s13201-024-02128-z.

[18] F. Amador-Castro, M. E. González-López, G. Lopez-Gonzalez, A. Garcia-Gonzalez, O. Díaz-Torres, O. Carbajal-Espinosa, and M. S. Gradilla-Hernández, "Internet of Things and citizen science as alternative water quality monitoring approaches and the importance of effective water quality communication," *Journal of Environmental Management*, vol. 352, p. 119959, 2024, doi: 10.1016/j.jenvman.2023.119959.

[19] M. A. Rahu, M. M. Shaikh, S. Karim, et al., "Water Quality Monitoring and Assessment for Efficient Water Resource Management through Internet of Things and Machine Learning Approaches for Agricultural Irrigation," *Water Resources Management*, vol. 38, pp. 4987–5028, 2024, doi: 10.1007/s11269-024-03899-5.

[20] L. Kumar, M. J. Deitch, I. A. Tunio, A. Kumar, S. A. Memon, L. Williams, U. Tagar, R. Kumari, and S. Basheer, "Assessment of physicochemical parameters in groundwater quality of desert area (Tharparkar) of Pakistan," *Environ. Monit. Assess.*, Year unknown.

[21] P. A. Suriasni, F. Faizal, W. Hermawan, U. Subhan, C. Panatarani, and I. M. Joni, "IoT Water Quality Monitoring and Control System in Moving Bed Biofilm Reactor to Reduce Total Ammonia Nitrogen," *Sensors*, vol. 24, no. 2, p. 494, Jan. 2024, doi: 10.3390/s24020494.

[22] W. A. Jabbar, T. M. Ting, M. F. I. Hamidun, A. H. C. Kamarudin, W. Wu, J. Sultan, A. A. Alsewari, and M. A. H. Ali, "Development of LoRaWAN-based IoT system for water quality monitoring in rural areas," *Expert Systems with Applications*, vol. 242, p. 122862, May 2024, doi: 10.1016/j.eswa.2023.122862.

[23] R. Wiryasaputra, C.-Y. Huang, Y.-J. Lin, and C.-T. Yang, "An IoT Real-Time Potable Water Quality Monitoring and Prediction Model Based on Cloud Computing Architecture," *Sensors*, vol. 24, no. 4, p. 1180, Feb. 2024, doi: 10.3390/s24041180.

[24] Y. Singh and T. Walingo, "Smart Water Quality Monitoring with IoT Wireless Sensor Networks," *Sensors*, vol. 24, no. 9, p. 2871, Apr. 2024, doi: 10.3390/s24092871.

[25] N. A. Mohd Jais, A. F. Abdullah, M. S. Mohd Kassim, M. M. Abd Karim, M. Abdulsalam, and N. 'Atirah, "Improved accuracy in IoT-Based water quality monitoring for aquaculture tanks using low-cost sensors: Asian seabass fish farming," *Heliyon*, vol. 10, no. 8, p. e29022, Apr. 2024, doi: 10.1016/j.heliyon.2024.e29022.

[26] H. Zeb, A. Yaqub, H. Ajab, I. Zeb, and I. Khan, "Effect of Climate Change and Human Activities on Surface and Ground Water Quality in Major Cities of Pakistan," *Water*, vol. 15, p. 2693, 2023, doi: 10.3390/w15152693.

[27] J. D. Suthar, I. Rajper, Z. ul-Hassan, N. Depar, and V. Suthar, "Ground-water quality in Islamkot and Mithi talukas of district Tharparkar, Sindh, Pakistan," *Mehran Univ. Res. J. Eng. Technol.*, vol. 38, no. 1, pp. 143–150, 2019, doi: 10.3316/informit.094605299894468.