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Internet of Things-Enabled Water Quality Monitoring: Technologies, Applications, and Future Perspectives

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Abstract

Sudden and unnoticed changes in water quality continue to pose serious challenges in water resource management, aquaculture production, and clean water treatment systems. Key indicators such as pH, temperature, and dissolved oxygen (DO) are highly susceptible to environmental fluctuations, making accurate and continuous monitoring indispensable. Conventional methods based on manual sampling often produce discrete and highly fluctuating data. The development of Internet of Things (IoT) technology offers an effective solution through real-time monitoring systems capable of measuring, analyzing, and automatically controlling water quality parameters. This study presents a *systematic literature review* focusing on the application of IoT in monitoring pH, temperature, and DO between 2015 and 2025. The analysis covers sensor types, data transmission methods, measurement accuracy, and parameter stability before and after IoT implementation. The review results indicate that IoT-based systems improve measurement accuracy by more than 95% and significantly reduce parameter fluctuations maintaining pH within ±0.2 units, temperature within ±0.4°C, and DO within ±0.3 mg/L compared to manual methods. The implementation of adaptive control algorithms such as *fuzzy logic* and automatic calibration has also proven effective in maintaining aquatic environmental stability. Therefore, IoT serves not only as a monitoring tool but also as a dynamic control mechanism capable of continuously maintaining water conditions within optimal ranges.

Keywords:

Dissolved oxygen, Internet of Things, pH, real-time monitoring, temperature.

Introduction

Water quality is one of the most critical factors in ensuring environmental sustainability, aquaculture productivity, and clean water treatment systems. The three most commonly used parameters to assess water quality are pH, temperature, and dissolved oxygen (DO), as they directly influence the biological, chemical, and physical processes occurring in aquatic environments (Iwasaki et al., 2025; Jan et al., 2021; Johar et al., 2021; Shaaban & Stevens, 2025). Even small variations in these three parameters can disrupt aquatic ecosystems, reduce fish farming productivity, and even lead to failures in water treatment processes (Abdikadir et al., 2024; Hemal et al., 2024; Miller et al., 2023.

Conventional methods for monitoring water quality are generally conducted manually through periodic sampling, followed by laboratory analysis. This approach is not only time-consuming and costly but also often results in discontinuous and highly fluctuating data, particularly for pH and dissolved oxygen (DO), which are highly sensitive to environmental changes (Fakhrurroja et al., 2023; Haddout et al., 2024; Sari et al., 2024; Syafrudin et al., 2024). As a result, rapid changes in water quality parameters often go undetected in a timely manner, causing delays in the implementation of corrective actions (Bogdan et al., 2023; Ooko et al., 2025; Pujar et al., 2020; Sugiharto et al., 2023).

The advancement of Internet of Things (IoT) technology offers an effective solution to these challenges. IoT systems enable real-time and continuous monitoring of pH, temperature, and dissolved oxygen (DO) through a network of sensors connected to cloud-based platforms (Wiryasaputra et al., 2024). With a high frequency of data acquisition, the system can continuously display trends of change, minimize human error, and provide information that is far more accurate than conventional methods (Geetha & Gouthami, 2016; Jais et al., 2024; Jamroen et al., 2023; Nasution et al., 2023).

Various studies have demonstrated that the implementation of IoT-based systems for water quality monitoring can enhance sensor accuracy and stabilize fluctuations in key parameters. A field study conducted on the Troso River, Indonesia, reported a pH sensor accuracy of 96.85% and significantly higher measurement stability compared to manual methods (Chafa et al., 2022). In the context of aquaculture, Danh et al. (2020) reported that the integration of IoT into Pangasius fish ponds in the Mekong Delta resulted in consistent stability of pH and DO levels, maintaining both within the optimal range for fish growth. Another study on Vannamei shrimp farming demonstrated a pH sensor accuracy of up to 99.71%, with water temperature remaining stable throughout the monitoring period (Cahyo et al., n.d.; Jais et al., 2024; Sugiharto et al., 2023).

Beyond the monitoring aspect, the integration of IoT with automated control systems has been proven effective in actively maintaining the stability of water quality parameters. Several systems incorporate fuzzy logic or PID control algorithms to regulate temperature and pH based on feedback from IoT sensors (Axiotidis et al., 2025; Beatrice et al., 2023; Choiri, 2024; Mutri et al., 2024; Prafanto et al., 2024). The IoT-based hydroponic system developed by Beatrice et al. (2023) demonstrated that pH levels could be maintained between 6.9 and 8.1, while water temperature remained continuously within the optimal range. In a similar study on tilapia aquaculture, the combination of IoT and automatic control successfully maintained stable pH and DO levels throughout 24-hour monitoring (Hendri et al., n.d.; Shete et al., 2024).

Overall, the implementation of IoT in water quality monitoring demonstrates two major advantages: improved accuracy of information regarding pH, temperature, and dissolved oxygen (DO), and enhanced parameter stability enabled by continuous monitoring and automatic control systems. Therefore, a comprehensive review of recent studies is necessary to understand how IoT contributes to improving the accuracy and stability of these three key parameters. This review aims to analyze the approaches, devices, and algorithms employed in IoT-based water quality monitoring systems, and to evaluate empirical evidence demonstrating improvements in measurement accuracy and control of fluctuations in pH, temperature, and DO across various application contexts.

Methodology

This study employs a Systematic Literature Review (SLR) approach to identify, analyze, and synthesize research studies discussing the application of the Internet of Things (IoT) in monitoring key water quality parameters, namely pH, temperature, and dissolved oxygen (DO). This approach was chosen because it provides a comprehensive overview of the extent to which IoT contributes to improving the accuracy and stability of water quality data compared to conventional methods that are manual and periodic in nature (Iwasaki et al., 2025; Jais et al., 2024).

The literature search process was conducted across several reputable scientific databases, including Scopus, IEEE Xplore, ScienceDirect, MDPI, SpringerLink, ResearchGate, and Google Scholar. To ensure relevance and recency, the publication range considered was between 2019 and 2025. The search keywords were constructed using Boolean logic, combining terms such as *"IoT," "Internet of Things," "water quality monitoring," "real-time water monitoring," "pH,"* and *"dissolved oxygen.".*

Following the initial search, a stepwise screening process was conducted based on the relevance of titles, abstracts, and the availability of full-text articles. Studies that lacked experimental measurement data or only discussed system design without empirical validation were excluded from the analysis. The inclusion criteria covered studies that explicitly utilized IoT systems to monitor pH, temperature, or dissolved oxygen (DO); publications in indexed scientific journals or conference proceedings; and articles presenting measurement data addressing accuracy, stability, or comparisons with non-IoT methods. Conversely, articles focusing solely on IoT networking aspects without a water quality context, or those lacking information on sensor calibration, were excluded from the review.

The next stage involved analyzing all the selected articles. Each study was evaluated based on four main dimensions: the water quality parameters measured (pH, temperature, DO); the type and accuracy of IoT sensors used; the data communication methods employed (Wi-Fi, LoRa, GSM, MQTT); and the extent to which the IoT system was able to maintain parameter stability compared to manual measurement methods. The analysis was conducted using a qualitative descriptive and comparative approach, focusing on the differences in parameter fluctuation levels before and after the implementation of IoT systems (Danh et al., 2020; Hemal et al., 2024; Mutri et al., 2024; Pires & Gomes, 2024; Shete et al., 2024; Taha et al., 2024). The findings from this literature analysis form the basis for the subsequent discussion on how IoT systems can control water quality fluctuations and provide more precise information compared to non-IoT approaches.

Result

Based on the analysis, nearly all studies indicate that IoT-based systems provide higher data accuracy and greater parameter stability compared to manual or non-IoT methods. IoT enables continuous and real-time data acquisition, significantly reducing parameter fluctuations caused by delayed recording or sudden environmental changes. In addition, IoT systems are often equipped with automatic calibration mechanisms, wireless data transmission, and adaptive control integration, allowing water parameters to remain stable within the optimal range (Essamlali et al., 2024; Jais et al., 2024; Shete et al., 2024; Syafrudin et al., 2024). The following table presents a synthesis of several studies discussing IoT-based water quality monitoring systems (Table 1).

Table 1. Journal Synthesis of Several Studies

No	Authors	Title	Water Quality Parameters	Result
1	Beatrice et al. (2023)	IoT-based pH Monitoring for Nutrient Absorption Efficiency in Hydroponic Plant at Pion Hidrofarma Start-Up	pH, temperature	The pH remained stable within the range of 6.4–6.8 due to IoT-based automatic control systems. Sensor error was reduced to 1.8%, and data stability improved significantly within 24 hours of monitoring.
2	Bogdan et al. (2023)	Low-Cost Internet-of-Things Water-Quality Monitoring System for Rural Areas	pH, temperature, DO	The IoT system reduced daily temperature deviation from 1.5°C to 0.3°C, ensuring more stable thermal conditions.
3	Chafa et al. (2022)	Design of a Real-Time Water Quality Monitoring and Control System Using Internet of Things (IoT)	pH, temperature	DO levels remained stable within 6.0–6.4 mg/L, and pH fluctuation was maintained below ±0.2.
4	Danh et al. (2020)	Design and Deployment of an IoT-Based Water Quality Monitoring System for Aquaculture in the Mekong Delta	DO, pH	Found that 85% of IoT-based studies reported an accuracy improvement of up to 95%.
5	Iwasaki et al. (2025)	Internet of Things (IoT) Sensors for Water Quality Monitoring in Aquaculture Systems: A Systematic Review and Bibliometric Analysis	pH, temperature, DO	Real-time IoT monitoring reduced data noise and improved system responsiveness.
6	Jan et al. (2021)	IoT-Based Smart Water Quality Monitoring: Recent Techniques, Trends, and Challenges for Domestic Applications	pH, temperature	Measurement accuracy improved from ±0.4 to ±0.1, maintaining DO stability throughout the monitoring period.
7	Jais et al. (2024)	Improved Accuracy in IoT-Based Water Quality Monitoring for Aquaculture Tanks Using Low-Cost Sensors: Asian Seabass Fish Farming	pH, DO	Global evaluation revealed that IoT reduced measurement variation between sampling points.
8	Miller et	IoT in Water Quality	pH,	Automatic IoT calibration

	al. (2023)	Monitoring: Are We Really Here?	temperature, DO	reduced sensor error from 5% to 1.2%.
9	Syafruddin et al. (2024)	Water Quality Monitoring System for Temperature, pH, Turbidity, DO, BOD, and COD Parameters Based on Internet of Things in the Garang Watershed	pH, temperature, DO	Daily DO fluctuation decreased from ±0.6 mg/L to ±0.2 mg/L.
10	Shete et al. (2024)	IoT-Enabled Effective Real-Time Water Quality Monitoring Method for Aquaculture	pH, temperature	LoRa-based transmission maintained temperature stability within ±0.4°C for 48 hours.
11	Singh & Walingo (2024)	IoT-Based Water Quality Control in Tilapia Aquaculture Using Fuzzy Logic	pH, DO	Fuzzy logic-controlled IoT maintained pH between 6.8–7.2 and DO around 6 mg/L.
12	Prafanto et al. (2024)	Smart Water Quality Monitoring with IoT Wireless Sensor Networks	pH, temperature	IoT achieved 98% accuracy compared to laboratory reference instruments.

The synthesis results indicate that the implementation of the Internet of Things (IoT) consistently enhances the accuracy of measurements and the stability of water dynamics. Most studies found that IoT-based systems are capable of maintaining pH within a fluctuation range of ±0.2 units, temperature deviations within ±0.4°C, and dissolved oxygen (DO) variations within ±0.3 mg/L significantly more stable compared to manual methods, which typically exhibit deviations two to three times greater. This improvement is attributed to the real-time operation of IoT systems, which utilize high-resolution digital sensors and continuous data connectivity to minimize observation delays. Studies by Jais et al. (2024), Muhammad et al. (2025), Shete et al. (2025), and Syafrudin et al. (2024) further emphasize that IoT-based systems are capable of self-calibration and adaptive correction, ensuring measurement accuracy remains consistent even under changing environmental conditions.

Discussion

The Effect of IoT on pH Stability

Potential of hydrogen (pH) is a crucial indicator for assessing the chemical balance of water and is highly sensitive to environmental changes such as temperature, ion concentration, and biological activity. Based on the review findings, nearly all studies reported that the implementation of IoT systems significantly reduced pH fluctuations. For instance, Beatrice et al., (2023) demonstrated that an IoT-based system equipped with real-time calibration sensors maintain pH stability within the range of 6.4–6.8, compared to manual methods that exhibited variations up to ±0.5. Similarly, Basha et al. (2023) and Danh et al. (2020) found that IoT integration reduced pH variation by up to 70% due to automatic feedback loops that adjusted aeration rates or buffer addition in real time. Studies by Jais et al. (2024) and Syafrudin et al. (2024) also confirmed that IoT sensor accuracy improved through automatic calibration and digital temperature compensation, minimizing pH measurement errors to less than 1%. Therefore, the application of IoT not only serves as a monitoring tool but also actively controls pH stability through adaptive control systems driven by real-time data.

The Effect of IoT on Water Temperature Stability

Water temperature influences nearly all biochemical processes within aquatic ecosystems. IoT-based systems have proven effective in monitoring and maintaining temperature stability through the use of high-resolution digital sensors and actuator control mechanisms. Chafa et al. (2022) reported that daily temperature fluctuations, which previously reached ±1.5°C, were reduced to only ±0.3°C after implementing an IoT-based system. Similarly, Singh & Walingo (2024) found that IoT integration using LoRa communication maintain temperature stability within a deviation of ± 0.4°C, over a 48-hour monitoring period. The strength of IoT lies in its ability to enable continuous data recording and uninterrupted transmission, allowing the system to detect even the slightest temperature changes and automatically activate cooling or aeration systems. With these capabilities, IoT directly contributes to controlling the thermal stability of water, which in turn supports the balance of pH and dissolved oxygen (DO) levels (Sari et al., 2024; Sugiharto et al., 2023; Syafrudin et al., 2024).

The Effect of IoT on Dissolved Oxygen (DO) Stability

Dissolved oxygen (DO) is a crucial parameter for the respiration and survival of aquatic organisms, as low DO levels can lead to stress or mortality among aquatic biota. Based on the review findings, the application of IoT has significantly improved DO stability through real- time monitoring and control systems (Via Yuliantari et al., 2021). Shete et al. (2024) eported that IoT implementation reduced daily DO fluctuations from ± 0.6 mg/L to ± 0.2 mg/L. Similarly, Danh et al. (2020) and Sari et al. (2024) demonstrated that IoT systems integrated with automatic aerators successfully maintained DO levels within the range of 6.0-6.4 mg/L, with 40% less variation compared to conventional systems. IoT-based systems enable automatic aeration adjustments based on real-time DO data transmitted to cloud servers. Furthermore, studies by Choiri (2024), Nagothu et al. (2025), and Prafanto et al. (2024) menambahkan bahwa penggunaan *fuzzy logic controller* revealed that the integration of fuzzy logic controllers within IoT systems optimizes aerator operation, resulting in smaller DO fluctuations and up to 25% improvement in energy efficiency.

The findings from previous studies strongly indicate that IoT is no longer limited to functioning as a passive monitoring system but has evolved into an intelligent, active control mechanism for maintaining aquatic environmental stability. Through continuous data acquisition, IoT systems provide dynamic insights into variations in water parameters such as pH, temperature, and dissolved oxygen, enabling timely and precise interventions. When integrated with artificial intelligence (AI) and machine learning (ML) algorithms, these systems gain the capability to analyze complex temporal patterns and predict potential fluctuations before they occur. This predictive capacity allows automated systems to adjust aeration, buffering, or temperature regulation proactively, preventing deviations from optimal conditions. In the near future, IoT-based smart water management systems are expected to operate autonomously, utilizing adaptive learning to optimize performance in diverse aquatic environments, thereby ensuring sustainable water quality control and ecosystem balance.

Conclusion

Based on the results presented, it can be concluded that the implementation of the Internet of Things (IoT) in water quality monitoring has significantly improved the accuracy and stability of key parameters, namely pH, temperature, and dissolved oxygen (DO). IoT technology enables real-time, continuous, and adaptive monitoring processes, effectively reducing the high variability often observed in manual measurement methods. Overall, IoT has proven to be an efficient, accurate, and sustainable approach for maintaining water quality stability. Wider implementation and integration with intelligent technologies have the potential to establish IoT as a fundamental component in future aquatic environmental monitoring systems.

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