UNIVERSIDAD NACIONAL DE SAN MARTÍN

RCSI
https://revistas.unsm.edu.pe/index.php/rcsi
e-ISSN: 2709-992X

Original article
Artículo original
Jul-Dec, 2026

IoT System for Water-Quality Monitoring in Intensive Tilapia Culture Using Biofloc

Sistema IoT para monitoreo de la calidad del agua en cultivo intensivo de tilapia con biofloc

García-Castro, Juan Carlos[1]*
Gálvez-Díaz, Marco Armando[1]
Riascos-Armas, Juan Orlando[1]
Hernández-Torres, Edwin Augusto[1]
Alva-Arévalo, Alberto[1]
Acosta-Jacinto, Rubén Eusebio[2]
Ríos-Julcapoma, Milton[2]

[1]Facultad de Ingeniería de Sistemas e Informática, Universidad Nacional de San Martín, Tarapoto, Peru
[2]Instituto Nacional de Investigación y Capacitación de Telecomunicaciones, Universidad Nacional de Ingeniería, Lima, Peru

Received: 02 Mar. 2026 | **Accepted:** 11 Jul. 2026 | **Published:** 20 Jul. 2026

Corresponding author*: jcgarcia@unsm.edu.pe

How to cite this article: García-Castro, J. C., Gálvez-Díaz, M.A, Riascos-Armas, J.O., Hernández-Torres, E.A., Alva-Arévalo, A., Acosta-Jacinto, R.E. y Ríos-Julcapoma, M. (2026). IoT System for Water-Quality Monitoring in Intensive Tilapia Culture Using Biofloc. *Revista Científica de Sistemas e Informática*, *6*(2), e1610. https://doi.org/10.51252/rcsi.v6i2.1610

ABSTRACT

Continuous water quality monitoring is essential in intensive tilapia farming systems using biofloc technology, where physicochemical variations can affect system stability and productive performance. This study implemented and evaluated an Internet of Things (IoT)-based system at the Ahuashiyacu Fishing Station in San Martín, Peru, to monitor temperature, pH, dissolved oxygen, and nitrate ion in real time. The system integrated sensors connected to a microcontroller with wireless transmission to a web platform for data storage and visualization. From November 2024 to September 2025, more than 22,000 measurements were recorded. Temperature remained between 24 and 27 °C, while dissolved oxygen ranged from 4 to 12 mg/L. Atypical pH readings and a temporary increase in nitrate ion levels were also identified. The results demonstrated the system's operational feasibility and usefulness for preventive water quality management.

Keywords: smart aquaculture; biofloc; Internet of Things; remote monitoring; sensors

RESUMEN

El monitoreo continuo de la calidad del agua es fundamental en sistemas intensivos de tilapia con tecnología biofloc, donde las variaciones fisicoquímicas pueden afectar la estabilidad y el desempeño productivo. En este estudio se implementó y evaluó un sistema basado en Internet de las Cosas (IoT) en la Estación Pesquera Ahuashiyacu, San Martín, Perú, para monitorear en tiempo real la temperatura, el pH, el oxígeno disuelto y el ion nitrato. El sistema integró sensores conectados a un microcontrolador con transmisión inalámbrica hacia una plataforma web para almacenar y visualizar los datos. Entre noviembre de 2024 y septiembre de 2025 se registraron más de 22 000 mediciones. La temperatura se mantuvo entre 24 y 27 °C y el oxígeno disuelto entre 4 y 12 mg/L. También se identificaron registros atípicos de pH y un incremento puntual del ion nitrato. Los resultados demostraron la viabilidad operativa del sistema y su utilidad para la gestión preventiva de la calidad del agua.

Palabras clave: acuicultura inteligente; biofloc; internet de las cosas; monitoreo remoto; sensores

1. INTRODUCTION

Tilapia is one of the most widely farmed species in global aquaculture because of its rapid growth, adaptability, and commercial demand (Estrada-Godinez et al., 2023). In Latin America, its production has experienced sustained growth in recent years (FAO, 2020; Hernandez-Martinez et al., 2025), particularly through intensive systems aimed at increasing productive yield and optimizing water use (Ingle de la Mora, 2003). In this context, water quality is a determining factor in maintaining appropriate farming conditions (Pérez-Somarriba et al., 2025), since variables such as temperature, pH, dissolved oxygen, and nitrogen compounds influence fish growth, survival, and productive performance (Delgado-Santillán et al., 2025; López Acopa et al., 2023).

In systems employing biofloc technology (BFT) (Landines, 2025), controlling these variables is particularly important because of the microbial activity associated with nutrient recycling and the stability of the aquatic environment (González-Reyes et al., 2024; Hernandez-Martinez et al., 2025). This technology improves resource utilization and reduces water exchange (Bado et al., 2024; Bossier & Ekasari, 2017); however, its operation depends on the continuous monitoring of the physicochemical conditions of the farming system (Gálvez-Cantero et al., 2022; García-Castro & Ascón-Dionisio, 2022). Variations in temperature, dissolved oxygen, pH, and nitrogen compounds, as well as the accumulation of organic matter and changes in microbial activity, can disrupt system stability and affect tilapia development (Garza-Martínez et al., 2021; Lee et al., 2017).

Traditionally, water quality control is performed through manual measurements and periodic records, which limits the timely identification of critical variations and hinders the continuous availability of information for monitoring the farming process (Medrano et al., 2024). In response to this situation, Internet of Things (IoT)-based technologies provide an alternative for automating data acquisition, transmitting measurements remotely, and displaying them through digital platforms (Carbajal-Hernández et al., 2017; Encinas et al., 2017). In the Peruvian context, IoT-based environmental monitoring initiatives have also been developed in aquaculture environments in the Amazon region, demonstrating the potential of these technologies for monitoring physicochemical parameters in locations with limited access and technological infrastructure (Lino Villarán, 2022).

Although research has addressed the application of IoT in aquaculture, a substantial proportion of existing proposals focuses on acquiring specific variables or transmitting data within controlled environments with stable communication infrastructure (Fuentes Amín & Romero Torres, 2024; Miranda Almendaris et al., 2025). Solutions are still required for intensive biofloc-based tilapia farming that integrate, within a single architecture, multiparameter data acquisition, local processing, measurement backup, wireless transmission, information management, and visualization through a web platform. This need is particularly relevant in Amazonian contexts, where environmental variability and technological limitations may hinder the continuous monitoring of water conditions.

In response to this need, the objective of this study was to develop an IoT system for monitoring temperature, pH, dissolved oxygen, and nitrate ions in intensive tilapia farming using biofloc technology. The proposed system integrated an ESP32-based electronic node, local processing and storage mechanisms, wireless communication, record management services, and a web platform for data consultation, visualization, and report generation. Accordingly, the study sought to establish a reproducible technological solution that facilitates the monitoring of physicochemical variables and supports the operational supervision of the farming system.

2. MATERIALS AND METHODS

2.1 Study Design and Scope

This research was applied and technological-development oriented, focusing on the construction and functional integration of a solution for monitoring water quality in intensive tilapia farming systems using biofloc technology. The Ahuashiyacu Fisheries Station, located in the San Martín region of Peru, was considered the reference setting, as its operational characteristics made it possible to establish the technical requirements associated with monitoring geomembrane-lined ponds. The development process was sequentially organized into four methodological components, through which the operating, communication, and information management specifications guiding the construction of the technological proposal were defined.

2.2 Proposed IoT System Architecture

The system architecture was organized into four functional layers, defined according to the operations required to transform the physicochemical conditions of the pond into information available to the user. This separation allowed the responsibilities related to acquisition, communication, management, and visualization to be distributed across different components, preventing the entire operation from being concentrated in a single element and facilitating the integration, maintenance, and future expansion of the solution.

The first layer corresponded to the IoT monitoring node, which was responsible for collecting measurements and performing their initial processing within the farming environment. The second layer comprised wireless communication, which was required to connect the device to the remote infrastructure without the need for a permanent physical connection. The third layer included the services and data management components responsible for receiving, organizing, and storing the generated records. Finally, the fourth layer consisted of the web platform, through which users accessed the water quality, production, feeding, and reporting modules. The relationship among these layers is presented in **Figure 1**.

Within this architecture, the IoT node constituted the component responsible for interacting directly with the farming environment and centralizing the initial acquisition of the monitored variables. Therefore, its electronic design was defined through the integration of the microcontroller, sensors, and auxiliary modules required for processing, recording, and transmitting the measurements.

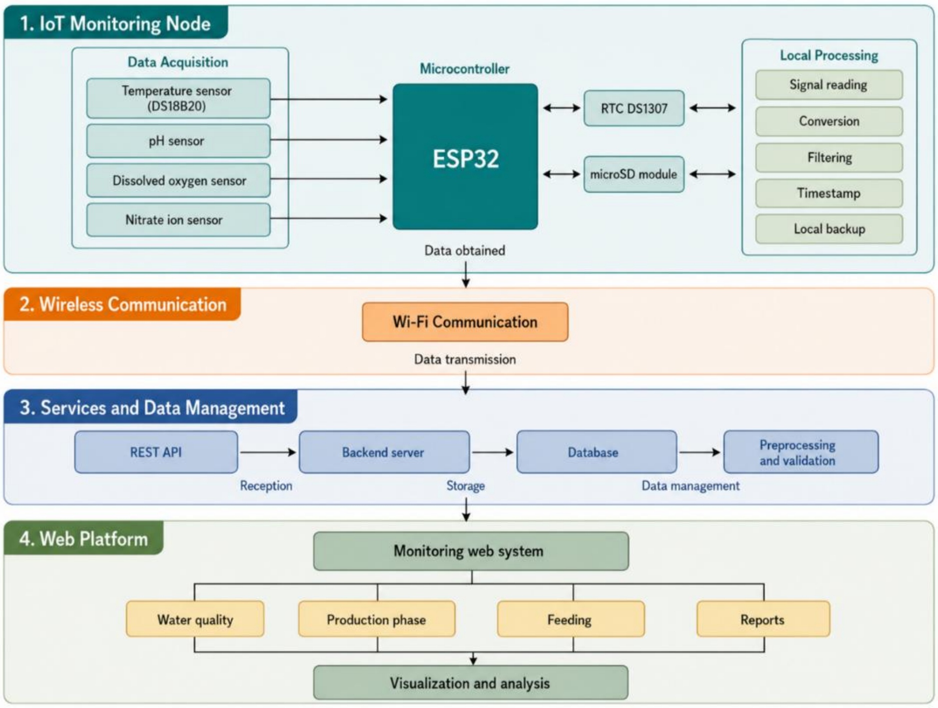

Figure 1. General architecture of the IoT system

2.3 Electronic Design of the IoT Node

The electronic design of the IoT node was structured around an ESP32 DevKit board, which served as the central unit for acquiring, processing, and transmitting the monitored variables. Its selection made it possible to integrate digital and analog inputs, communication interfaces for auxiliary modules, and Wi-Fi connectivity into a single device, thereby reducing the need for an external wireless module. The general arrangement of the components and their connections is shown in **Figure 2**.

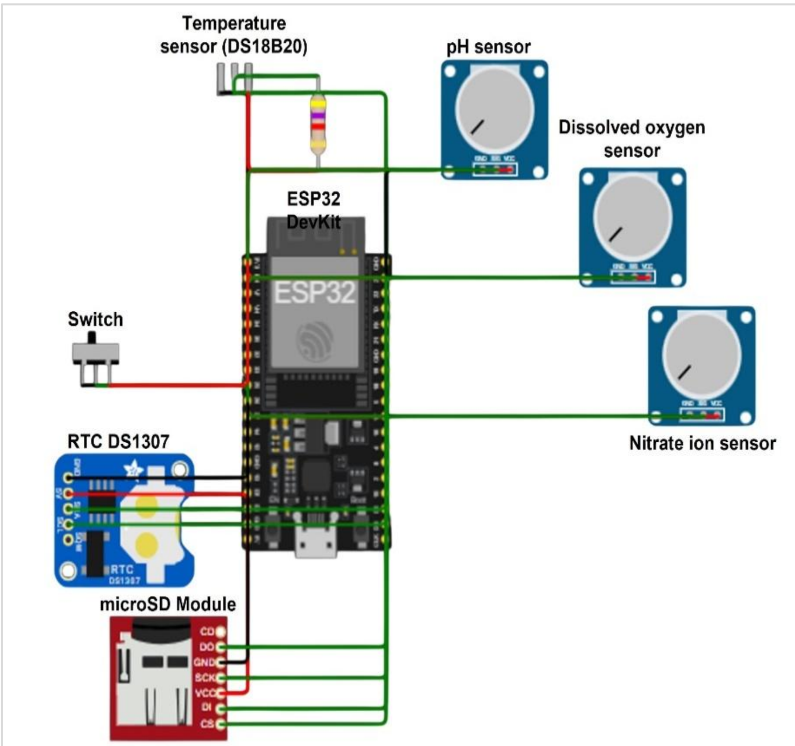

Figure 2. Electronic design of the IoT node

A DS18B20 digital sensor was incorporated for temperature measurement and connected to the ESP32 through a data line and a 4.7 kΩ pull-up resistor to maintain communication stability. The signals corresponding to pH, dissolved oxygen, and nitrate ions were connected to independent analog inputs of the microcontroller, allowing each variable to be acquired and processed separately. In the diagram, these three inputs are represented by adjustable analog signal modules associated with each physicochemical variable.

The node also included a DS1307 real-time clock module, responsible for providing the date and time of each measurement, and a microSD module for the local storage of records. The RTC communicated with the ESP32 through the I^2C interface, whereas the microSD module used the SPI interface for data exchange. A switch was also incorporated to control circuit activation, and a common power and ground reference was established among the electronic components.

This configuration concentrated signal reading, timestamp assignment, local backup, and record preparation functions within the node before wireless transmission. The integration of the auxiliary modules also enabled measurements to be retained whenever the connection to the server was unavailable, thereby supporting the continuity of variable recording.

Once the electronic integration of the device had been defined, the functional workflow through which measurements were acquired, processed, transmitted, stored, and displayed on the web platform was established.

2.4 Functional Workflow of the IoT System

Once the general architecture and electronic integration of the IoT node had been defined, the functional workflow guiding the system's operation was established. This workflow was organized into eight sequential and interrelated stages, ranging from the definition of physicochemical variables and device configuration to data processing, transmission, management, and visualization. Its structure provided a comprehensive representation of the path followed by the data and defined the activities performed within the farming environment, information services, and web platform, as shown in **Figure 3**.

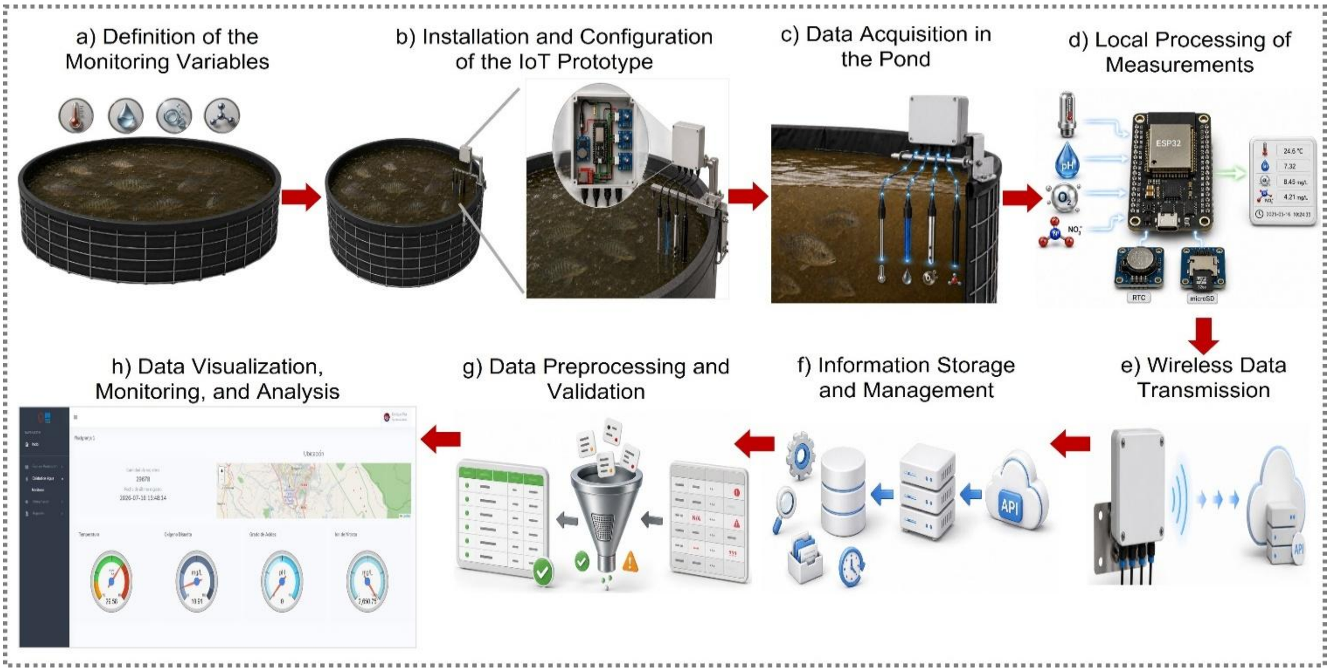

Figure 3. Functional workflow of the IoT system

a) Definition of the Monitoring Variables

Temperature, pH, dissolved oxygen, and nitrate ions were selected as monitoring variables based on their relevance to controlling the physicochemical conditions of water in intensive tilapia farming systems using biofloc technology. This selection covered four complementary aspects of the aquatic environment: the thermal behavior of the pond, acid–base balance, oxygen availability, and the presence of nitrogen compounds associated with biofloc dynamics (Garza-Martínez et al., 2021).

Temperature was recorded in degrees Celsius (°C), pH on its dimensionless scale, and dissolved oxygen and nitrate ion concentrations in milligrams per liter (mg/L). The possibility of obtaining these variables using sensors compatible with the IoT node and integrating them into a single acquisition, storage, and visualization process was also considered. The technical characteristics and connections of the selected devices were previously described in the electronic design of the system.

b) Installation and Configuration of the IoT Prototype

The IoT node was installed at the edge of the pond using a support structure that kept the electronic enclosure away from direct contact with water while positioning the probes inside the farming environment. The four sensors were arranged independently, ensuring stable immersion and sufficient separation to reduce possible interference during measurements. The wiring was also secured to the support structure to prevent displacement caused by aeration, water movement, or routine production management activities.

The configuration included assigning the ESP32 inputs for each variable, synchronizing the RTC module, enabling storage on the microSD card, and establishing the Wi-Fi connection. The reading and transmission intervals were also defined, along with the structure used to record the date, time, and value of each measurement. Before data acquisition began, the operation of the components was verified, and the parameters required to integrate the temperature, pH, dissolved oxygen, and nitrate ion readings into a single monitoring process were adjusted (Encinas et al., 2017; García-Castro & Ascón-Dionisio, 2022).

c) Data Acquisition in the Pond

Once the IoT node had been configured, the sensors measured temperature, pH, dissolved oxygen, and nitrate ions directly in the pond water. Each device detected variations in its corresponding variable and transferred the signal to the ESP32 through the digital or analog inputs assigned during system configuration. Measurements were performed sequentially within a one-minute sampling cycle. During each cycle, the ESP32 consecutively queried the four sensors and grouped the values obtained under the same timestamp, thereby generating periodic records and maintaining monitoring continuity.

During this stage, the probes remained submerged in the designated area of the pond and secured to the support structure to reduce displacement caused by water circulation and aeration. The acquired values served as inputs for the subsequent conversion, organization, and recording operations performed locally by the microcontroller.

d) Local Processing of Measurements

Following acquisition, the ESP32 converted the received signals into their corresponding units and calculated the average of five consecutive readings to reduce momentary variations associated with water movement and aeration. It then verified that the values were within the configured ranges and organized them into a structured record that included the date and time provided by the DS1307 RTC module. Finally, each record was backed up on the microSD card before being transmitted to the server.

e) Wireless Data Transmission

The generated records were transmitted every 20 minutes through the Wi-Fi connection integrated into the ESP32. The data accumulated during this interval were structured in JSON format and sent to the server through an HTTP POST request directed to the system's REST API. This transmission frequency reduced network traffic and supported operation in environments with variable connectivity. When transmission could not be completed, the records remained stored on the microSD card and were automatically resent once the connection was restored.

f) Information Storage and Management

Once received by the API, the records were verified and stored in the database according to the pond, monitored variable, and corresponding timestamp. This organization preserved the measurement history, facilitated data retrieval, and kept the information available for queries performed through the web platform. The server also managed the incorporation of new records and prevented the duplicate storage of previously processed data.

g) Data Preprocessing and Validation

Before visualization, the records underwent an automatic quality-control process. First, the presence of the date and time, pond identification, and values corresponding to the four monitored variables was verified. The temporal consistency of the measurements was then reviewed, and possible duplicate records were identified by comparing their timestamps and ponds of origin. The system also verified whether the values were within the configured ranges for each parameter and identified abrupt variations relative to previous readings.

Incomplete, duplicate, or out-of-range records were flagged for review and temporarily excluded from indicator calculations without being removed from the database. Finally, records considered valid were chronologically ordered and prepared for consultation, graphical representation, and report generation through the web platform.

h) Data Visualization, Monitoring, and Analysis

The web platform was developed using Python and the Django framework. Django REST Framework was used to integrate communication services, while PostgreSQL was employed to manage the records. The interface was implemented using HTML5, CSS3, and JavaScript, complemented by Bootstrap to adapt its display to different devices and Chart.js to graphically represent the behavior of the monitored variables.

The platform was organized into home, water quality, production phase, feeding, and reporting modules. The water quality module displayed temperature, pH, dissolved oxygen, and nitrate ion values, together with the date of the latest measurement, the number of available records, and the pond location. It also enabled users to examine the temporal evolution of the variables through graphs and tables. The reporting module facilitated record searches by time period and data export in CSV format, integrating the visualization, monitoring, and retrieval functions for the data generated by the IoT system.

3. RESULTS

3.1 Functional Implementation of the Web Platform

The developed web platform centralized the consultation and monitoring of the information generated by the IoT system. The interface integrated functions related to production management and water quality monitoring, organizing access through specific modules. **Figure 4** presents the main implemented interfaces: the home dashboard, the water quality monitoring module, and the reporting module.

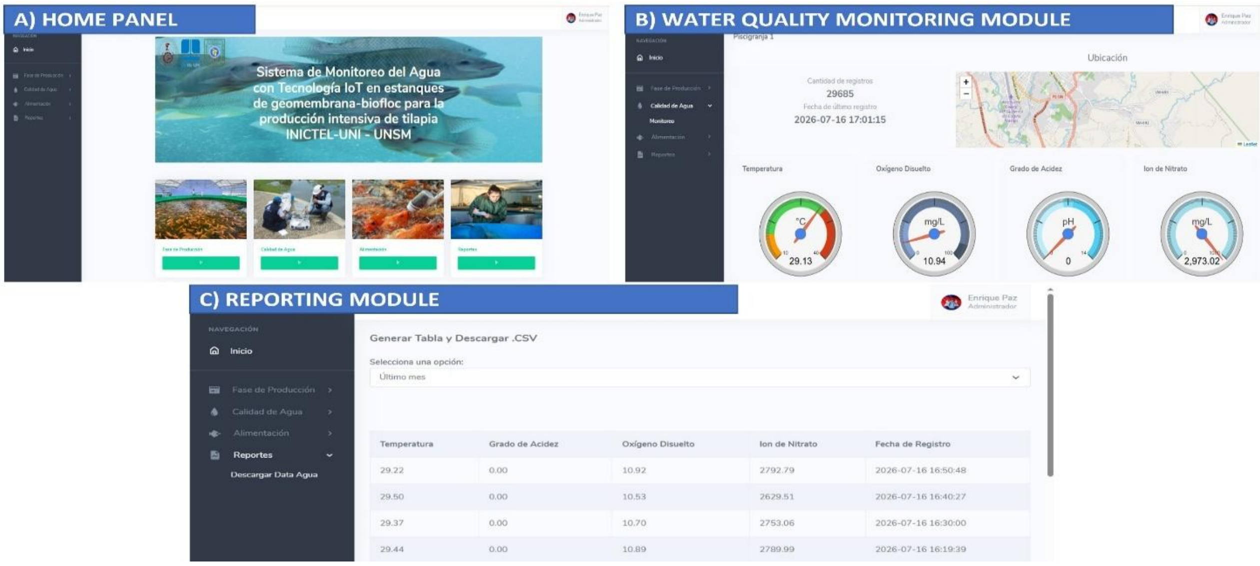

Figure 4. Functional modules of the web platform

The home dashboard—**Figure 4(a)**—provided access to the water quality, production phase, feeding, and reporting modules, facilitating navigation among the available functions. The water quality monitoring module—**Figure 4(b)**—displayed the recorded values of temperature, pH, dissolved oxygen, and nitrate ions, together with the date of the latest measurement, the number of stored records, and the pond location. This arrangement enabled an integrated consultation of the variables considered for monitoring the physicochemical conditions of the farming system.

The reporting module—**Figure 4(c)**—enabled users to consult the measurement history using time-based search criteria and to view the available records. It also included an option to export the information in CSV format to facilitate subsequent processing and analysis. Overall, the implemented interfaces integrated the consultation of recent measurements, historical monitoring, and information retrieval within a single platform.

3.2 General Behavior of the Physicochemical Variables

Table 1 summarizes the behavior observed for the physicochemical variables during the monitoring period, highlighting their predominant ranges, extreme values, and events that required particular review. Overall, temperature showed the most stable behavior, whereas pH, dissolved oxygen, and nitrate ions exhibited relevant variations during April 2025.

Table 1. Summary of results by physicochemical variable (observed range and relevant events)

Parameter	Range/Behavior	Relevant event	Consideration
Temperature (°C)	Predominantly 24–27 (stable and suitable)	No extreme values outside the recommended range were observed.	It showed the greatest temporal stability.
pH	Fluctuated around 7.5–8.2	Anomalous peak in April 2025 (31.88), attributable to an error or calibration issue.	The record was flagged for review because of a possible reading, calibration, or processing error.
Dissolved oxygen (mg/L)	Varied between 4 and 12, with a decreasing trend toward April	Minimum value of 4.78 mg/L in April; increased aeration was recommended.	The decrease indicated the need to strengthen aeration control.
Nitrate ion (mg/L)	Remained below 1,000 throughout the period	April 2025: 990.22 mg/L, close to the critical threshold.	The record approached the reference limit considered and required monitoring.

Temperature remained stable during most of the period, without abrupt changes. In contrast, pH reached a value of 31.88 in April 2025, which is incompatible with the conventional pH scale. Therefore, it was considered an anomalous record possibly associated with calibration, reading, or processing errors.

Dissolved oxygen decreased to 4.78 mg/L in April, indicating lower oxygen availability. This variation may have been related to biomass, microbial activity, and organic matter accumulation, highlighting the importance of maintaining adequate aeration.

The nitrate ion concentration reached 990.22 mg/L in April 2025. Although it remained below the established limit, its proximity indicated a relevant accumulation of nitrogen compounds. Overall, April showed the greatest variability in the physicochemical conditions of the water.

3.3 Temporal Evolution of the Physicochemical Variables

Figure 5 complements the previous results by showing the temporal evolution of temperature, pH, dissolved oxygen, and nitrate ions during the analyzed period. Overall, temperature exhibited moderate variations, whereas dissolved oxygen showed a decrease between 2024 and 2025. In contrast, pH and nitrate ion concentration recorded their greatest variations in April 2025, coinciding with the relevant events previously identified.

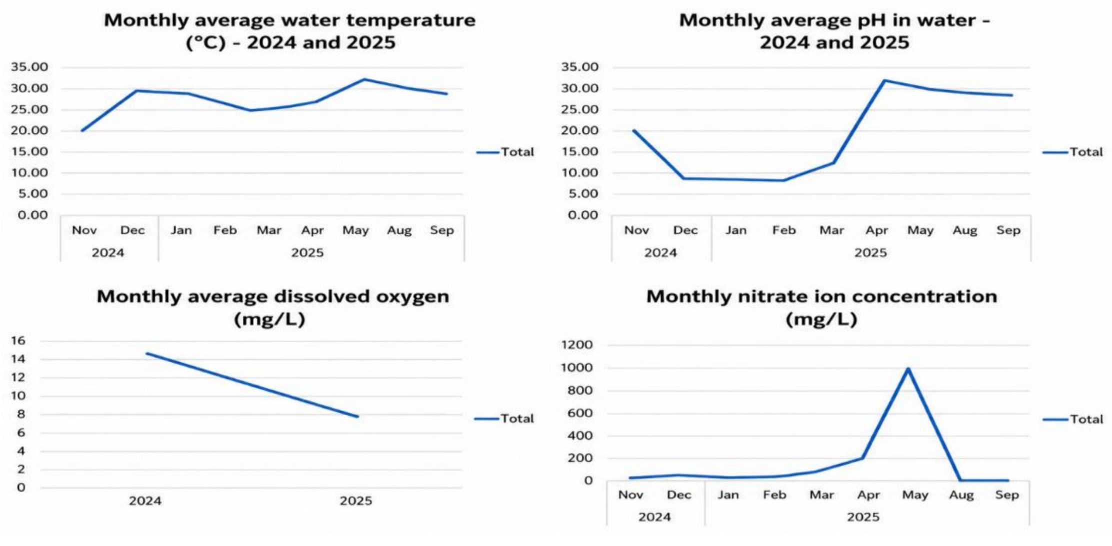

Figure 5. Temporal evolution of the monitored physicochemical variables

3.4 Overall System Performance

During operation, the system recorded temperature, pH, dissolved oxygen, and nitrate ion values, associated each measurement with its corresponding timestamp, and stored the information for subsequent consultation. The platform also displayed the most recent values, the measurement history, and the pond location, while enabling data export in CSV format. Overall, these functions demonstrated the operational integration of the electronic components, data management services, and web interface.

3.5 Discussion

The results showed that the IoT system successfully integrated the acquisition, transmission, storage, and visualization of the physicochemical variables considered for monitoring intensive tilapia farming using biofloc technology. The availability of records through the web platform facilitated the observation of temporal changes and the identification of values requiring review, such as the anomalous pH record detected in April 2025. These findings are consistent with Zhu et al. (2010) and Piamba-Mamian et al. (2020), who indicate that remote monitoring systems improve the continuous availability of information and support water quality monitoring in aquaculture environments.

Among the variables evaluated, temperature exhibited relatively stable behavior, whereas dissolved oxygen decreased during the analyzed period. This parameter is particularly relevant in intensive systems because of the oxygen consumption associated with biomass, microbial activity, and organic matter decomposition. Accordingly, Zhou et al. (2022) emphasize the need for continuous dissolved oxygen monitoring to prevent unfavorable conditions in aquaculture systems. Similarly, Quintero Sanchez et al. (2024) highlight that monitoring physicochemical variables contributes to maintaining the stability of biofloc systems and supporting proper culture development.

Nitrate ion concentration reached its highest level in April 2025, coinciding with the period of greatest variability observed in the other measurements. However, this behavior should be interpreted cautiously because the recorded concentration was considerably higher than those observed during the remaining months. Likewise, the pH value of 31.88 was outside the physically valid scale for this variable and was therefore considered an anomalous record, possibly related to calibration problems, signal conversion, or data processing. These events demonstrate the importance of incorporating validation controls and periodic calibration procedures to improve measurement reliability.

The integration of the electronic node with the management services and web platform made it possible to combine monitoring, historical consultation, and report generation within a single solution. This result supports the usefulness of IoT technologies in facilitating remote access to information and reducing dependence on manual records, in agreement with the applications reported by Gamarra Moreno et al., (2024). Nevertheless, the evaluation focused mainly on the integrated operation of the system and the analysis of the available records. Therefore, future evaluations should incorporate metrics related to availability, packet loss, latency, energy consumption, connection stability, and post-calibration accuracy to quantitatively determine system performance over prolonged operating periods.

CONCLUSIONS

The developed IoT system integrated the acquisition, processing, storage, and periodic visualization of temperature, pH, dissolved oxygen, and nitrate ion measurements in an intensive tilapia farming system using biofloc technology. The records obtained facilitated the identification of temporal variations and outliers, demonstrating the usefulness of the solution for monitoring the physicochemical conditions of the water.

The integration of the electronic node, wireless communication, data management services, and web platform centralized the consultation of recent measurements, access to historical records, and report generation. Thus, the system served as a technological support tool for reducing dependence on manual records and facilitating the operational supervision of intensive aquaculture systems.

For future work, the system should be evaluated over longer periods and under different operating conditions, incorporating metrics related to availability, latency, data loss, energy consumption, and post-calibration accuracy. Automatic alert mechanisms and predictive models could also be integrated to support the early detection of critical variations in water quality.

ACKNOWLEDGMENTS

The authors thank the Ahuashiyacu Fishing Station and the Universidad Nacional de San Martín for providing the facilities required to conduct the field tests, as well as the technical staff and students who contributed to the installation, validation, and commissioning of the prototype. The institutional support provided by INICTEL-UNI in the design and testing stages is also gratefully acknowledged.

FINANCING

The project was funded through the faculty research project competition approved by Resolution No. 611-2022-UNSM/CU-R, with additional support from Executing Unit 002-INICTEL-UNI under the agreement approved by Resolution No. 331-2026-UNSM/CU-R.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest related to this work.

AUTHORSHIP CONTRIBUTION

Conceptualization: García-Castro, J.C. and Acosta-Jacinto, R.E.; Data Curation: Gálvez-Díaz, M.A. and Hernández-Torres, E.A.; Formal Analysis: Riascos-Armas, J.O. and Alva-Arévalo, A.; Funding Acquisition: García-Castro, J.C. and Acosta-Jacinto, R.E.; Investigation: García-Castro, J.C. and Acosta-Jacinto, R.E.; Methodology: Rios-Julcapoma, M. and Gálvez-Díaz, M.A.; Project Administration: García-Castro, J.C. and Acosta-Jacinto, R.E.; Resources: Gálvez-Díaz, M.A. and Rios-Julcapoma, M.; Hardware Development: Acosta-Jacinto, R.E. and Rios-Julcapoma, M.; Software Development: Riascos-Armas, J.O. and Acosta-Jacinto, R.E.; Supervision: García-Castro, J.C. and Acosta-Jacinto, R.E.; Validation: Hernández-Torres, E.A. and Alva-Arévalo, A.; Visualization: Gálvez-Díaz, M.A. and García-Castro, J.C.; Writing – Original Draft: Riascos-Armas, J.O.; and Writing – Review & Editing: Acosta-Jacinto, R.E.

REFERENCES

Bado, M., Carneiro, J., & Guerra, I. (2024). Impacto de la tecnología BIOFLOC en el reciclaje de nutrientes, el bienestar animal y la sostenibilidad del ecosistema. *Revista Investigaciones Agropecuarias*, *7*(1), 88–98. https://doi.org/10.48204/j.ia.v7n1.a6548

Bossier, P., & Ekasari, J. (2017). Biofloc technology application in aquaculture to support sustainable development goals. *Microbial Biotechnology*, *10*(5), 1012–1016. https://doi.org/10.1111/1751-7915.12836

Carbajal-Hernández, J. J., Sánchez-Fernández, L. P., Hernández-Bautista, I., & Hernández-López, J. (2017). Modelo basado en redes neuronales artificiales para la evaluación de la calidad del agua en sistemas de cultivo extensivo de camarón. *Tecnología y Ciencias Del Agua*, *08*(5), 71–89. https://doi.org/10.24850/j-tyca-2017-05-05

Delgado-Santillán, L. Y., Trigoso, M., Mamani M., G. C., Mendoza, L., & De La Cruz, R. (2025). Water quality and production parameters of gray tilapia (Oreochromis niloticus) cultivation in earth pond. *AgroScience Research*, *3*(1), 27–38. https://doi.org/10.17268/agrosci.2025.003

Encinas, C., Ruiz, E., Cortez, J., & Espinoza, A. (2017). Design and implementation of a distributed IoT system for the monitoring of water quality in aquaculture. *2017 Wireless Telecommunications Symposium (WTS)*, 1–7. https://doi.org/10.1109/WTS.2017.7943540

Estrada-Godinez, J. A., Rodríguez-Montes de Oca, G. A., Pacheco-Marges, M. del R., & Bañuelos-Vargas, M. I. (2023). Desempeño productivo de hembras de tilapia, Oreochromis niloticus, en diferentes métodos de cultivo. *Revista MVZ Córdoba*, *28*(3), e3251. https://doi.org/10.21897/rmvz.3251

FAO. (2020). *El estado mundial de la pesca y la acuicultura 2020* (La sostenibilidad en acción. (ed.); La sosteni). FAO. https://doi.org/10.4060/ca9229es

Fuentes Amín, O. C., & Romero Torres, M. E. (2024). Diseño de un sistema de monitoreo de calidad de agua basado en IoT, aplicado a unidades de producción acuícola. *Revista Facultad de Ciencias Básicas*, *19*(1), 47–58. https://doi.org/10.18359/rfcb.7395

Gálvez-Cantero, L., Julián-Ricardo, M. C., & Ramos-Sánchez, L. B. (2022). El Biofloc en la acuicultura. *Centro Azúcar*, *49*(2), 136–146.

Gamarra Moreno, A. H., Taipe Castro, J. A., Arellano Vilchez, M. A., Lozano Paulino, Y. D., & Suazo Maldonado, Á. C. (2024). Sistema de monitoreo basado en IoT para la medición de calidad de agua de riego. *Prospectiva Universitaria*, *20*(1), 31–39. https://doi.org/10.26490/uncp.prospectivauniversitaria.2023.20.1972

García-Castro, J., & Ascón-Dionisio, G. (2022). Sistema automatizado de monitoreo de parámetros físico-químicos en producción de alevines Gamitana (Colossoma macropomum). *Revista Agrotecnológica Amazónica*, *2*(1). https://doi.org/10.51252/raa.v2i1.240

Garza-Martínez, M. Á., Alonzo-Rojo, F., Valenzuela-García, A. A., Nava-Camberos, U., Salcido-Gameros, D., Estrada-Arellano, J. R., & Cardoza-Martínez, G. F. (2021). Aptitud territorial para cultivo de tilapia (Oreochromis niloticus) con tecnología biofloc en el estado de Durango, México. *Ecosistemas y Recursos Agropecuarios*, *8*(3). https://doi.org/10.19136/era.a8n3.3049

González-Reyes, E., Espinosa-Chaurand, D., Hernández-Almeida, O., Cortés-Sánchez, A., Palomino-Hermosillo, A., & Peraza-Gómez, V. (2024). Biofloc en el tratamiento de aguas residuales del cultivo de peces. *Abanico Veterinario*, *15*. https://doi.org/10.21929/abavet2024.18

Hernandez-Martinez, I. Y., Salazar Sánchez, M. D. R., & Pereira Flores, L. F. (2025). Eficiencia productiva de la tilapia oreochromis sp criados en estanque de geomembrana con tecnología biofloc y raceways. *BISTUA REVISTA DE LA FACULTAD DE CIENCIAS BASICAS*, *23*(1), 1–8. https://doi.org/10.24054/bistua.v23i1.2936

Ingle de la Mora, G. (2003). Evaluación de algunos parámetros de calidad del agua en un sistema cerrado de recirculación para la acuicultura, sometido a diferentes cargas de biomasa de peces. *Hidrobiológica*, *13*(4), 247–253.

Landines, M. A. (2025). Tecnología biofloc en la acuicultura: estado de avance, desarrollo y aplicación. *Orinoquia*, *27*(1). https://doi.org/10.22579/20112629.826

Lee, C., Kim, S., Lim, S.-J., & Lee, K.-J. (2017). Supplemental effects of biofloc powder on growth performance, innate immunity, and disease resistance of Pacific white shrimp Litopenaeus vannamei. *Fisheries and Aquatic Sciences*, *20*(1), 15. https://doi.org/10.1186/s41240-017-0059-7

Lino Villarán, A. H. (2022). Sistema de monitoreo de ambiente para el control de las condiciones ambientales de las granjas acuícolas de la selva del Perú basado en Internet de las Cosas. *Interfases*, *16*(016), 140–167. https://doi.org/https://doi.org/10.26439/interfases2022.n016.6026

López Acopa, N. de J., Antonio Cruz, R. del C., Méndez de los Santos, N., Jesús de la Cruz, K. de M., & Romellón Cerino, M. J. (2023). Evaluación de los parámetros para la calidad del agua en el cultivo de tilapia. *REVISTA IPSUMTEC*, *6*(5), 52–59. https://doi.org/10.61117/ipsumtec.v6i5.212

Medrano, K., Hernández, E., Tejada, R., & Moreno, A. (2024). Tecnologías IoT para el monitoreo de la calidad del agua en la acuicultura. *European Public & Social Innovation Review*, *10*, 1–16. https://doi.org/10.31637/epsir-2025-929

Miranda Almendaris, R. H., Acebo Vera, A. A., Cevallos Zhunio, J. E., & Mejía Burgos, L. I. (2025). Prototipo de IoT para monitorear los parámetros del agua de un cultivo acuícola. *Investigación, Tecnología e Innovación*, *17*(24), 34–45. https://doi.org/10.53591/iti.v17i24.2539

Pérez-Somarriba, E. B., Hernández-Espinoza, K. M., Avendaño-Díaz, M. M., & Hernández-Bautista, M. F. (2025). Uso de agua residual del cultivo de tilapia (Oreochromis niloticus) como una alternativa productiva en el cultivo de maíz (Zea mays L). *Rev. Iberoam. Bioecon. Cambio Clim.*, *10*(20), 2484–2491. https://doi.org/10.5377/ribcc.v10i20.21912

Piamba-Mamian, T. M., Zambrano, L. E., Montaño Rúales, L. A., & Rojas Gonzales, F. A. (2020). Implementación de un sistema de monitoreo IoT aplicado a una piscicultura de trucha. *Informador Técnico*, *85*(1). https://doi.org/10.23850/22565035.2937

Quintero Sanchez, Y. D., Sanchez Portillo, S., Bracho Colina, E., Salazar Sanchez, M. del R., Pereira Florez, L. F., & Hernandez Martinez, I. (2024). Evaluación de la producción de tilapia roja (oreochromis sp) criados con tecnologia biofloc. *Revista EIA*, *21*(42). https://doi.org/10.24050/reia.v21i42.1761

Zhou, X., Wang, J., Huang, L., Li, D., & Duan, Q. (2022). Modelling and controlling dissolved oxygen in recirculating aquaculture systems based on mechanism analysis and an adaptive PID controller. *Computers and Electronics in Agriculture*, *192*, 106583. https://doi.org/10.1016/j.compag.2021.106583

Zhu, X., Li, D., He, D., Wang, J., Ma, D., & Li, F. (2010). A remote wireless system for water quality online monitoring in intensive fish culture. *Computers and Electronics in Agriculture*, *71*, S3–S9. https://doi.org/10.1016/j.compag.2009.10.004