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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

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ABSTRACT

Continuous water quality monitoring is essential in intensive tilapia farming systems based on biofloc technology, where physicochemical variations can directly affect environmental stability and overall productive performance. In this study, an Internet of Things (IoT)-based system was implemented and evaluated at the Ahuashiyacu Fisheries Station, San Martín, Peru, to periodically monitor temperature, pH, dissolved oxygen, and nitrate ion. The system integrated sensors connected to an IoT node with wireless transmission to a web platform for storing, consulting, and visualizing the collected data. Between November 2024 and September 2025, more than 22,000 measurements were recorded during field operation. Temperature remained between 24 and 27 °C, whereas dissolved oxygen ranged from 4 to 12 mg/L throughout the monitoring period. Atypical pH records and a temporary increase in nitrate ion were also identified in the dataset. The results demonstrated the system's operational feasibility and its usefulness as a technological tool for the continuous technical monitoring and supervision of water quality conditions.

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 periódicamente la temperatura, el pH, el oxígeno disuelto y el ion nitrato. El sistema integró sensores conectados a un nodo IoT 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 evidenciaron la viabilidad operativa del sistema y su utilidad para el seguimiento técnico continuo 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 due to its rapid growth, adaptability, and commercial demand (Estrada-Godinez et al., 2023). In Latin America, its production has shown sustained growth in recent years (FAO, 2020; Hernandez-Martinez et al., 2025), particularly through intensive systems aimed at increasing production performance and optimizing water use (Ingle de la Mora, 2003). In this context, water quality is a determining factor for maintaining appropriate culture conditions (Pérez-Somarriba et al., 2025), because variables such as temperature, pH, dissolved oxygen, and nitrogenous compounds influence fish growth, survival, and productive performance (Delgado-Santillán et al., 2025; López Acopa et al., 2023).

In systems using biofloc technology (BFT) (Landines, 2025), control of 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 can improve resource use and reduce water exchange (Bado et al., 2024; Bossier & Ekasari, 2017); however, its performance depends on continuous monitoring of the physicochemical conditions of the culture system (Gálvez-Cantero et al., 2022; García-Castro & Ascón-Dionisio, 2022). Variations in temperature, dissolved oxygen, pH, and nitrogenous compounds, as well as the accumulation of organic matter and changes in microbial activity, can alter system stability and affect tilapia development (Garza-Martínez et al., 2021; (Lee et al., 2017)).

Traditionally, water quality control is carried out through manual measurements and periodic records, which limits the timely identification of critical variations and hinders the continuous availability of information for culture monitoring (Medrano et al., 2024; Villaseñor-Reyes et al., 2026). In response to this situation, Internet of Things (IoT)-based technologies provide an alternative for automating data acquisition, remotely transmitting measurements, and presenting 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 several studies have addressed the application of IoT in aquaculture, a substantial proportion of the proposed solutions have focused on the acquisition of specific variables or on data transmission within controlled environments with stable communication infrastructure (Fuentes Amín & Romero Torres, 2024; Miranda Almendaris et al., 2025). Solutions are still needed for intensive tilapia culture using biofloc technology that integrate, within a single architecture, multiparameter data acquisition, measurement processing, autonomous power supply, wireless transmission, record storage, and visualization through a web platform. This need is particularly relevant in Amazonian contexts, where connectivity limitations and unstable electricity supply may hinder continuous monitoring of water conditions.

In response to this need, the present study aimed to develop and implement an IoT system for monitoring temperature, pH, dissolved oxygen, and nitrate ion in intensive tilapia culture using biofloc technology. The solution integrated an electronic node consisting of an ESP32-based LILYGO T-SIM7600G board mounted on a custom printed circuit board, sensors communicating via RS485-Modbus RTU, a local display, an autonomous solar power supply system, and wireless connectivity for transmitting records to a web platform. The information system incorporated a server developed using Django, a MySQL database, and an interface designed to provide access to recent measurements, historical monitoring, and data retrieval. In this way, the study sought to provide an integrated technological solution that would facilitate the monitoring of physicochemical variables and support the operational supervision of the culture system.

2. MATERIALS AND METHODS

2.1 Study Design and Scope

This was an applied research study with a technological development and integration component, aimed at designing and implementing an IoT-based solution for monitoring water quality in intensive tilapia culture using biofloc technology. The study was conducted at the Ahuashiyacu Fisheries Station, located in the San Martín Region, Peru, where the system was installed and functionally validated in a geomembrane-lined pond under real operating conditions. The procedure was organized into five components: system architecture, hardware implementation, software implementation, hardware–software integration, and field validation. This sequence enabled the development of the prototype and verification of the data acquisition, transmission, storage, and visualization workflow.

2.2 General Architecture of the IoT System

The system was organized into four components: an IoT monitoring node, wireless communication, data management services, and a web platform. This configuration structured the flow of information from data collection in the pond to its retrieval and visualization by the user.

The node integrated temperature, pH, dissolved oxygen, and nitrate ion sensors installed on a floating structure. Sensor readings were received via RS485-Modbus RTU on a custom PCB incorporating a LILYGO T-SIM7600G unit, a TTL–RS485 converter, a DS3231 RTC, and an OLED display. Power was supplied by a solar panel, charge controller, and battery.

The processed values were structured in JSON format and transmitted through HTTP POST requests. On the server side, an API implemented in Django verified the access key and received fields before storing the records in a MySQL database.

The web platform displayed recent measurements, historical records, and graphs of the monitored variables, as well as the pond location and an option to export the records. The implemented architecture and the relationships among its components are shown in **Figure 1**.

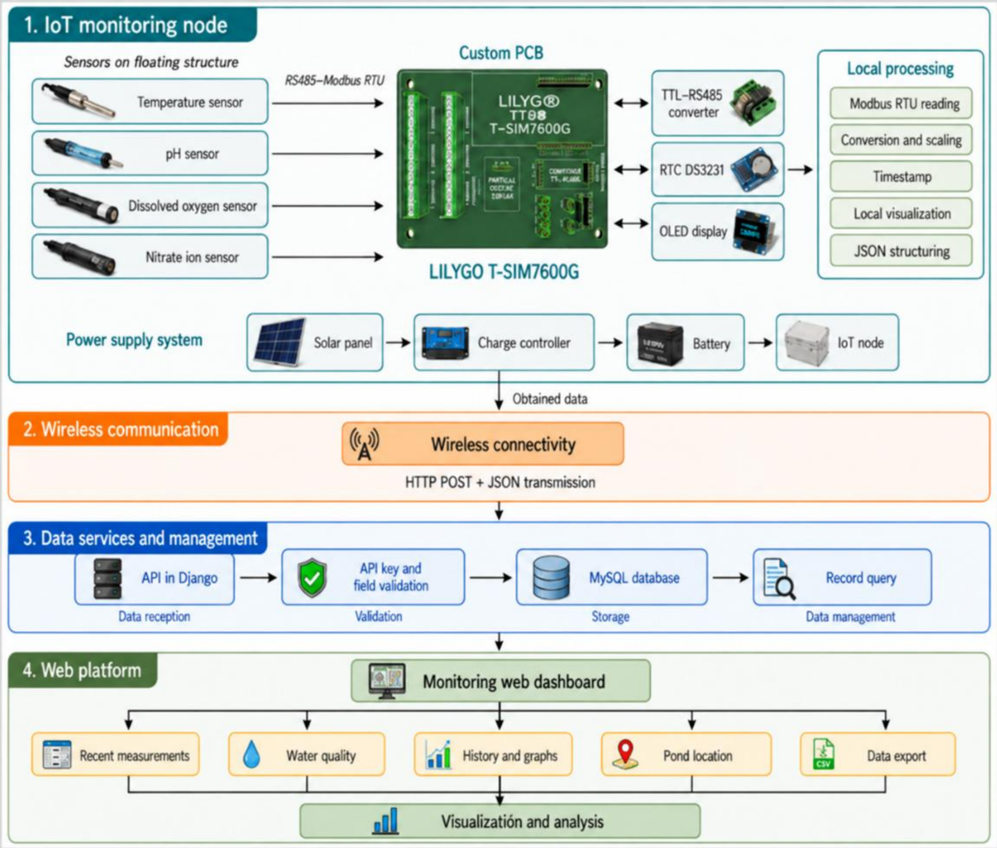

Figure 1. General architecture of the IoT system

2.3 Hardware Design and Implementation

2.3.1 IoT Node Components

The IoT node was designed around a custom PCB intended to integrate the LILYGO T-SIM7600G unit, communication interfaces, auxiliary modules, and power connections. The board incorporated a TTL–RS485 converter for communication with the sensors via Modbus RTU, a DS3231 real-time clock, a 128 × 64-pixel I^2C OLED display, and terminal blocks for connecting external devices. The main components considered in the design are presented in **Table 1**.

Table 1. Main hardware components of the IoT system

Component	Description	Function in the system
Processing unit	LILYGO T-SIM7600G	Reading, processing, and transmission of measurements.
Custom PCB	Board designed for the prototype	Electrical integration and distribution of connections.
Communication converter	TTL–RS485	Data exchange with the sensors via Modbus RTU.
Real-time clock	DS3231 RTC	Incorporation of a time reference into the records.
Local display	128 × 64 I^2C OLED	Visualization of readings during operation.
Sensors	Temperature, pH, dissolved oxygen, and nitrate ion	Measurement of the physicochemical variables of the water.
Protective enclosure	Upper control enclosure	Housing for the PCB, modules, and wiring.
Solar panel	Photovoltaic module	Energy generation for the system.
Charge controller	Digital controller	Regulation of battery charging and power supply to the node.
Battery	Energy storage unit	Power supply when direct power was unavailable.

Floating structure	Metal frame with four floats	Support and positioning of the probes within the pond.

2.3.2 Three-Dimensional Design of the Prototype

Based on these components, a three-dimensional design was developed to define the overall arrangement of the upper enclosure, PCB, power supply system, and structure intended to support the sensors. The model served as a reference for organizing the physical assembly and positioning of the main components, as shown in **Figure 2**.

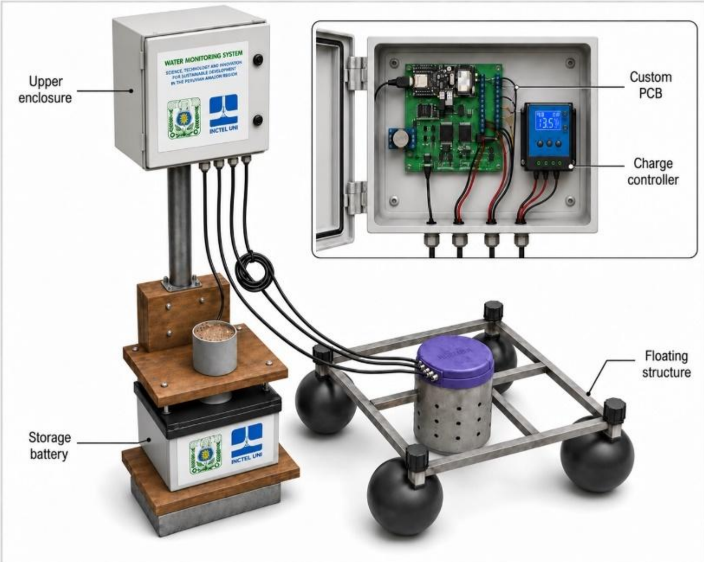

Figure 2. Three-dimensional design of the physical prototype of the IoT system
Note. Three-dimensional representation used as a guide for the assembly and overall arrangement of the enclosure, custom PCB, power supply system, and floating structure.

2.3.3 Functional Simulation of the Connections

Prior to assembly, the functional connections of the node were also represented using a simulation environment. Because the custom PCB and some prototype devices were not available in the software library, equivalent components were used: the LILYGO T-SIM7600G unit was replaced with an ESP32 board, the DS3231 RTC with a DS1307, and the pH, dissolved oxygen, and nitrate ion signals with adjustable modules; a DS18B20 sensor was used for temperature. The representation is shown in **Figure 3**.

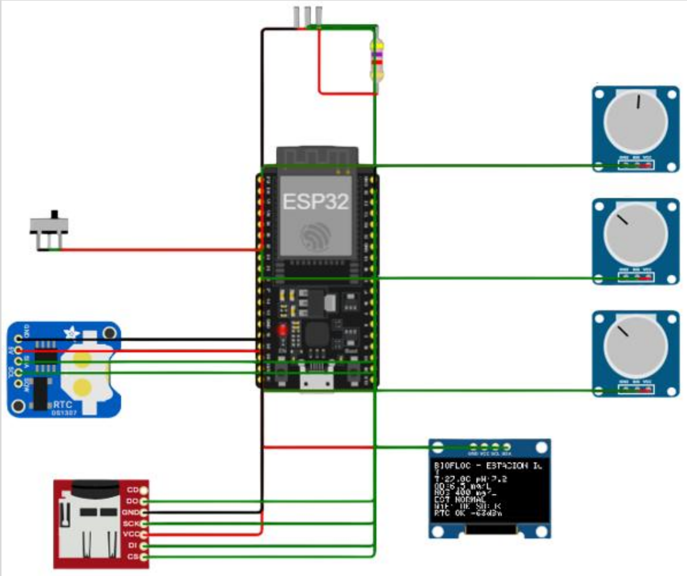

Figure 3. Simulated functional representation of the IoT node connections
Note. The simulation used equivalent components available in the software to represent the general connection logic; therefore, it does not correspond to the exact physical design of the custom PCB.

During the simulation, the variable values were modified to verify their reading and simultaneous visualization on the OLED display. The test made it possible to observe the node response to the introduced changes and verify the basic correspondence between the simulated inputs and the displayed values. The connections were simplified according to the capabilities of the software and therefore did not reproduce the RS485-Modbus RTU interface used in the physical prototype.

2.3.4 Prototype Assembly and Installation

Once the layout and connections had been defined, the PCB, charge controller, and wiring were installed inside the upper enclosure attached to a support structure. The power system was configured using a solar panel connected to the charge controller and a storage battery because of the instability of the electrical supply at the Ahuashiyacu Fisheries Station. Four cables corresponding to the probes installed in the pond extended from the enclosure.

The sensors were arranged on a floating structure consisting of a metal frame, four flotation elements, and a central cylindrical housing. The cables entered through the side of the cover, and the probes were distributed inside the housing while remaining in contact with the water during monitoring. This configuration provided a relatively stable position and allowed the probes to be removed for inspection, cleaning, and calibration activities.

2.3.5 Sensor Verification and Calibration

As part of the sensor verification procedure, pH 4.00, 6.86, and 9.18 buffer solutions were first prepared and used as reference values (Figure 4a) (Encinas et al., 2017; García-Castro & Ascón-Dionisio, 2022). The probe was then immersed in each solution to verify its response (Figure 4b), and the resulting readings were compared with those recorded by a portable meter (Figure 4c). Based on this comparison, the corresponding adjustments were made through the calibration interface (Figure 4d). For the remaining probes, inspection and cleaning activities were performed to remove adhered residues that could affect their operation during monitoring. The procedure applied to the pH sensor is shown in **Figure 4**.

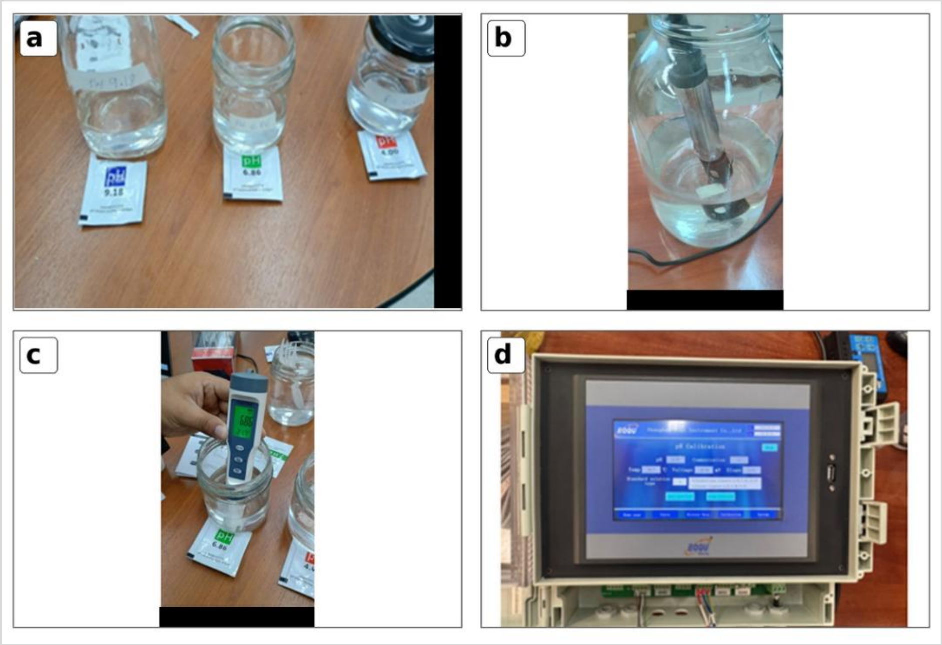

Figure 4. Verification and calibration of the pH sensor
Note. The procedure involved immersing the probe in buffer solutions, comparing the readings with those obtained using a portable meter, and adjusting the sensor through the calibration interface.

2.4 Software Design and Implementation

2.4.1 Backend and API Development

The software component was developed in Python using the Django framework, which was responsible for managing the reception, processing, and retrieval of the measurements generated by the system. For data input, an API was implemented with an endpoint designed to receive HTTP POST requests containing data structured in JSON format. The fields corresponded to temperature, pH, dissolved oxygen, and nitrate ion variables, together with the information required to temporally identify each record.

The backend logic was organized to interpret the received data, verify its structure, and manage its incorporation into the system. This implementation made it possible to separate the measurement reception process from the functions used for data storage and presentation on the web platform.

2.4.2 Data Validation and Storage

Before a measurement was recorded, the server verified the access key included in the request and the presence of the required fields. When the information met the established conditions, the values were processed and stored; otherwise, the request was rejected to prevent incomplete or unauthorized records from entering the system.

The information was organized in a MySQL database, which stored the values corresponding to the four monitored variables together with their time reference. This structure made it possible to maintain a measurement history and retrieve records according to the query requirements of the platform. phpMyAdmin was used for database administration, review, and maintenance tasks.

2.4.3 Web Platform Development

The web platform was designed to facilitate access to the information recorded by the IoT system. The interface displayed recent measurements of temperature, pH, dissolved oxygen, and nitrate ion, allowing users to review the status of the monitored variables from a centralized environment.

Functions were also incorporated to access the historical records and graphically represent the behavior of the variables over time. These options facilitated the identification of variations among measurements and the review of information corresponding to previous periods. In addition, the platform included the location of the monitored pond and a function for exporting the available records.

2.4.4 Access to and Retrieval of Information

The platform was accessed through a web browser, enabling users to consult the measurements without relying on a locally installed application. From the interface, users could view recent values, review historical records, examine graphs, and download the stored information for subsequent analysis.

The implemented functions were intended to centralize the information generated during monitoring and facilitate its availability to personnel responsible for technical follow-up. The complete integration among the sensor node, server, database, and web platform, as well as the tests conducted to verify their combined operation, are described in Section 2.5.

2.5 Integration and Functional Validation of the IoT System

2.5.1 Integration of the Node with the Web Server

System integration was carried out by connecting the IoT node to the web server developed in Django. After acquiring temperature, pH, dissolved oxygen, and nitrate ion measurements, the processing unit organized the values for transmission through wireless communication. The data were structured in JSON format and sent to the server through HTTP POST requests.

Upon receiving a request, the server verified the access key and the presence of the required fields. Accepted records were stored in the MySQL database and made available for access through the web platform. In this way, a continuous flow was established from variable acquisition to server reception, storage, and subsequent visualization. This process is represented in **Figure 5**.

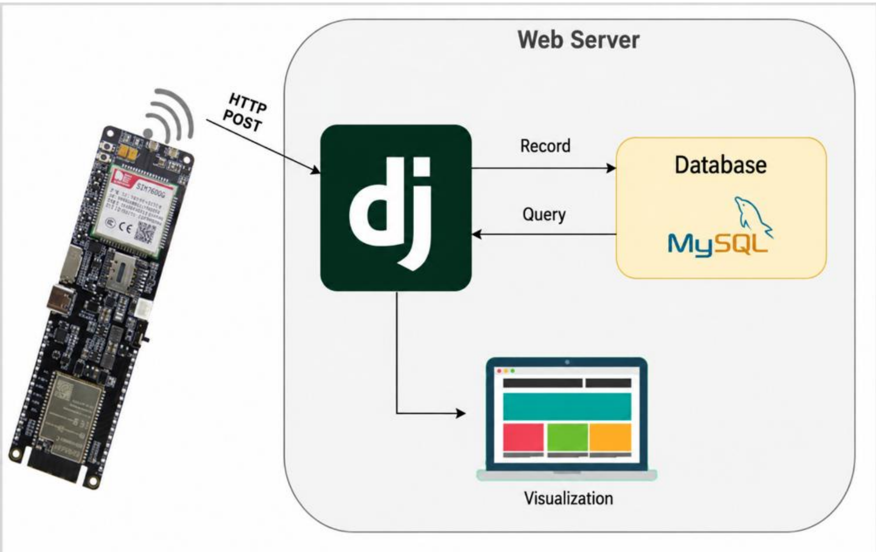

Figure 5. Integration flow between the IoT node and the web server

Note. Measurements obtained by the node were transmitted through HTTP POST requests, processed by the server developed in Django, stored in MySQL, and displayed on the web platform.

2.5.2 System Integration Tests

The integration tests were aimed at verifying the combined operation of the sensor station, web server, database, and user interface. For this purpose, readings were generated from the node and their transmission to the endpoint configured on the server was verified. During this procedure, the reception of requests, data validation, and creation of the corresponding records in MySQL were examined.

Subsequently, it was verified that the stored measurements could be retrieved and displayed on the platform. The review included visualization of recent values, consultation of historical records, and graphical representation of the variables. The availability of the information for export was also verified to confirm that the data could be retrieved for subsequent analyses.

The tests made it possible to evaluate the information flow through the following stages: sensor reading, processing at the node, transmission to the server, request validation, database storage, and presentation to the user. When interruptions or inconsistencies were identified, the connections, communication configuration, and structure of the transmitted data were reviewed before the test was repeated.

2.5.3 Field Installation and Validation

Once communication among the components had been verified, the system was installed in a geomembrane-lined pond using biofloc technology at the Ahuashiyacu Fisheries Station. The control enclosure and power supply system were positioned on the support structure, while the floating assembly was placed in the pond to keep the probes in contact with the water during monitoring.

Functional validation was conducted under the actual operating conditions of the aquaculture unit. During this stage, the acquisition of the four variables, transmission of the measurements, their recording in the database, and availability of the information on the web platform were verified. Periodic inspections of the probes and connections were also performed because prolonged exposure to water and organic matter could affect the stability of the readings.

The evaluation focused on verifying the integrated operation of the system and the continuity of the data flow. Therefore, it constituted a technological and operational validation rather than a metrological assessment of sensor accuracy against certified instruments.

2.5.4 Operational Transfer

As part of system deployment, personnel involved in the project were instructed on the use of the platform and remote access to the measurements. This familiarization included reviewing recent values, accessing historical records, interpreting the graphs, and retrieving stored records. The activity was intended to facilitate the use of the generated information for technical monitoring of water quality.

3. RESULTS AND DISCUSSION

3.1 Implementación física del prototipo IoT

The implementation resulted in a functional prototype consisting of the electronic node, protective enclosure, power supply system, and floating structure for the probes. The system was installed in the biofloc unit at the Ahuashiyacu Fisheries Station, with the electronic components protected and the sensors maintained in contact with the water. The final configuration enabled the integration of the four probes, the photovoltaic system, and the control unit into a structure suitable for field operation. The main components of the prototype and their installation are shown in **Figure 6**.

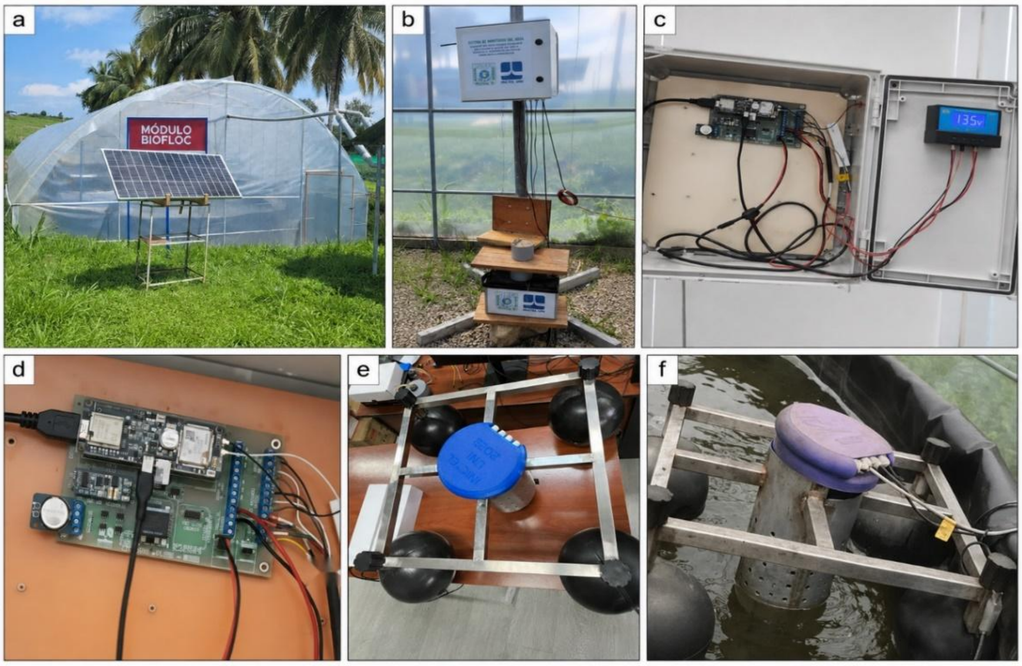

Figure 6. Physical implementation of the IoT prototype in the biofloc unit
Note. a) Biofloc unit and solar power supply system; b) support structure with the control enclosure and battery; c) internal arrangement of the electronic components; d) custom PCB; e) assembled floating structure; f) floating structure installed in the pond.

3.2 Web Platform Operation

The web platform centralized the information generated by the IoT node and made it available to users through a query interface. The system included a home dashboard, a water quality monitoring module displaying records, variable indicators, and the location of the unit, as well as a reporting module for tabular data consultation and downloading data in CSV format. The main implemented views are shown in **Figure 7**.

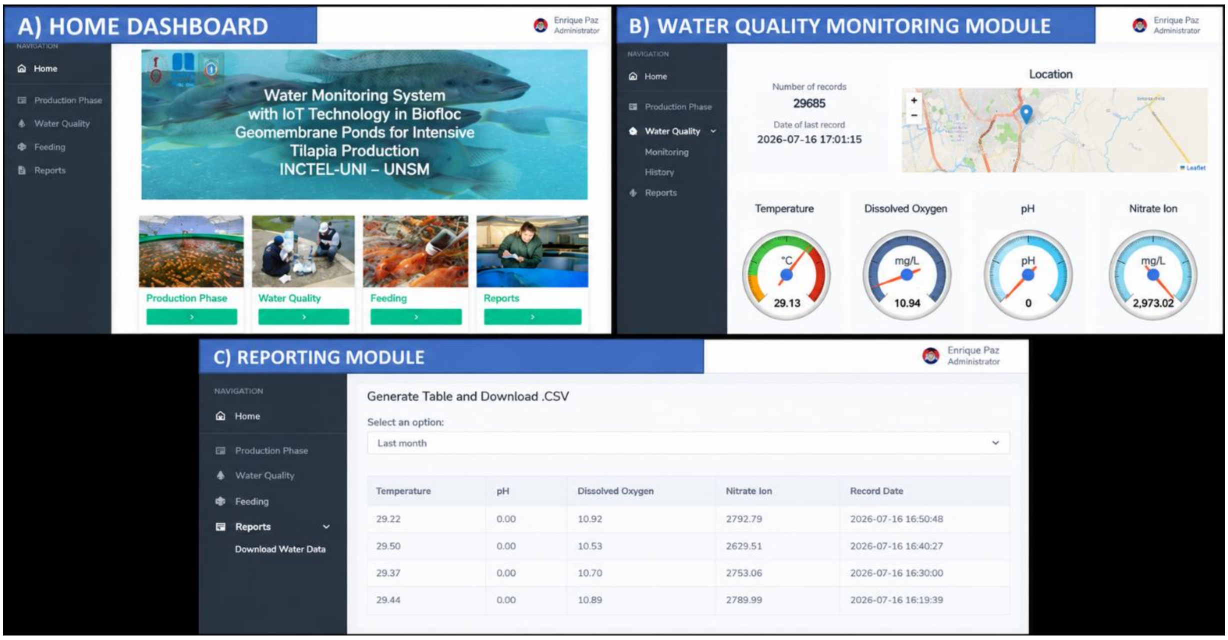

Figure 7. Physical implementation of the IoT prototype in the biofloc unit

Note. a) Home dashboard; b) water quality monitoring module showing the number of records, date of the most recent record, location, and indicators for temperature, dissolved oxygen, pH, and nitrate ion; c) reporting module for tabular data consultation and downloading data in CSV format.

3.3 General Behavior of the Physicochemical Variables

Table 2 summarizes the behavior observed for the physicochemical variables during the monitoring period, highlighting their predominant ranges, extreme values, and events requiring particular review. Overall, temperature exhibited the most stable behavior, whereas pH, dissolved oxygen, and nitrate ion showed relevant variations during April 2025.

Table 2. Summary of results by physicochemical variable (observed range and relevant events)

Parameter	Range/Behavior	Relevant event	Consideration
Temperature (°C)	Predominantly ranged from 24–27 (stable and adequate)	No extreme values outside the recommended range were observed.	It was the variable with the greatest temporal stability.
pH	Fluctuated around 7.5–8.2	Anomalous peak in April 2025 (31.88), attributable to error/calibration.	The record was flagged for review because of a possible reading, calibration, or processing error.
Dissolved oxygen (mg/L)	Varied between 4–12, with a decreasing trend toward April	Minimum of 4.78 mg/L in April; enhanced aeration was recommended.	The decrease indicated the need to strengthen aeration control.
Nitrate ion (mg/L)	Remained below 1000 during the monitoring period	April 2025: 990.22 mg/L (close to the critical threshold).	The record approached the reference limit considered and required follow-up.

Temperature remained stable throughout most of the monitoring period, without abrupt changes. In contrast, pH reached a value of 31.88 in April 2025, which is incompatible with the conventional pH scale and was therefore considered an anomalous data point, 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 the accumulation of organic matter, highlighting the importance of maintaining adequate aeration.

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

3.4 Temporal Evolution of the Physicochemical Variables

Figure 8 complements the previous results by showing the temporal evolution of temperature, pH, dissolved oxygen, and nitrate ion during the analyzed period. In general, temperature showed moderate variations, whereas dissolved oxygen exhibited a decrease between 2024 and 2025. In contrast, pH and nitrate ion showed their greatest variations in April 2025, coinciding with the relevant events identified previously.

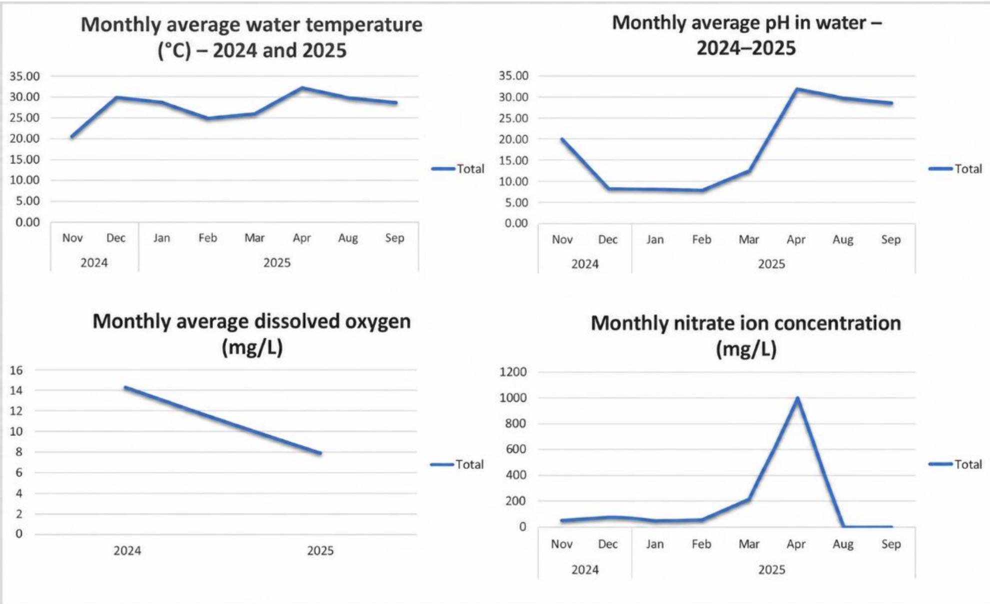

Figure 8. Temporal evolution of the monitored physicochemical variables

3.5 Overall System Operation

During operation, the system recorded temperature, pH, dissolved oxygen, and nitrate ion, associating each reading with its corresponding timestamp and storing it for subsequent consultation. The platform displayed recent measurements, historical records, and the pond location, while also allowing the information to be downloaded in CSV format. Overall, these results confirmed the integrated operation of the electronic node, data management services, and web interface.

3.6 Discussion

The integration of the electronic node, data management services, and web platform provided a unified solution for recording and accessing the physicochemical variables of tilapia culture using biofloc technology. Access to historical records facilitated the review of temporal changes and the detection of measurements requiring verification, such as the anomalous pH value recorded in April 2025. This finding is consistent with Zhu et al. (2010) and Piamba-Mamian et al. (2020), who highlight the usefulness of remote monitoring systems for improving the availability of water quality information in aquaculture environments.

Temperature showed relatively stable behavior throughout the analyzed period, whereas dissolved oxygen exhibited a decreasing trend. This variable requires particular attention in intensive systems because its concentration may be affected by cultured biomass, microbial activity, and the decomposition of organic matter. Zhou et al. (2022) emphasize the importance of monitoring this parameter to promptly identify unfavorable conditions, while Quintero Sanchez et al. (2024) indicate that monitoring physicochemical variables contributes to maintaining the stability of biofloc systems.

Nitrate ion reached its highest value in April 2025, a period during which greater variability in the records was also observed. However, this result should be interpreted with caution because of the considerable difference compared with the other months. Similarly, the pH value of 31.88 was outside the physically admissible range for this variable and was therefore considered anomalous. These measurements may have been associated with calibration problems, probe conditioning, signal conversion, or data processing. Their identification highlights the need to incorporate automatic validation rules, alerts for out-of-range values, and periodic cleaning and recalibration procedures.

The developed solution facilitated remote access, historical data review, and record export, thereby reducing dependence on manual record-keeping. This result is consistent with IoT applications in aquaculture described by Gamarra Moreno et al., (2024). However, the evaluation focused on the functional integration of the system and the analysis of stored data, without quantitatively measuring aspects such as availability, packet loss, latency, energy consumption, or sensor accuracy. Therefore, future evaluations should incorporate these metrics and compare sensor readings with reference instruments after calibration to determine system performance over prolonged periods of operation.

CONCLUSIONS

The developed IoT system enabled the recording, processing, storage, and visualization of temperature, pH, dissolved oxygen, and nitrate ion in an intensive tilapia culture system using biofloc technology. The collected data facilitated the analysis of temporal variations and the detection of atypical records, demonstrating the usefulness of the solution as a support tool for monitoring the physicochemical conditions of the water.

The integration of the electronic node, wireless communication, data management services, and web platform centralized access to recent measurements, historical records, and data export. In this way, the solution reduced dependence on manual record-keeping and facilitated the operational monitoring of the aquaculture unit. However, the evaluation primarily verified the integrated operation of the system rather than its metrological performance.

As future work, it is recommended to evaluate the solution over longer periods and under different operating conditions, incorporating metrics such as availability, latency, data loss, energy consumption, and sensor accuracy after calibration. The implementation of automatic alerts and predictive models would also be appropriate to support the timely identification of critical variations in water quality.

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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

Villaseñor-Reyes, G., Nájera-Alemán, P., Acosta-Pérez, V.-J., Rabling-Olivera, J., González-Vázquez, J., Ubilla-Paredes, K.-P., Bell-Palacios, I.-S., Gómez-de-Anda, F.-R., & Zepeda-Velázquez, A.-P. (2026). Correlación de la calidad del agua y la comunidad parasitaria en Cyprinus carpio var. koi en Pachuca de Soto, Hidalgo, México. *Revista Peruana de Investigación Agropecuaria*, *5*(1), e145. https://doi.org/10.56926/repia.v5i1.145

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