A Low-Cost IoT System Development for Real-Time Residential Water Monitoring

Andrea Monserrath Fernández-Saldaña, Alejandro Monroy-Avelino, Pedro Miranda-Romagnoli, *Senior Member, IEEE*, and Roberto Noriega-Papaqui

***Abstract*—Water, as a natural resource, faces increasing pressure globally due to climate change, urbanization, and poor management, highlighting the need for accessible technological solutions for its monitoring. In this paper, we present the design of a low-cost system, that uses Internet of Things (IoT), for real-time monitoring of water consumption and level in residential environments (applicable to infrastructure in Mexico). The IoT system integrates a Hall-effect-based sensor for flow measurement, a level sensor based on a pressure difference, and a data acquisition and cloud communication unit. Additionally, an interface was developed to enable real-time monitoring of water consumption, allowing users to understand and modify their consumption habits. The experimental results demonstrate the viability and effectiveness of the proposed solution as a scalable, low-cost alternative for smart water monitoring in urban environments.**

Link to graphical and video abstracts, and to code:
https://latamt.ieeer9.org/index.php/transactions/article/view/11019

***Index Terms*—Water monitoring, Internet of Things, water resources, pressure sensors, flow sensors, ESP32.**

I. Introduction

CURRENTLY, water resources are significantly affected by climate change worldwide [1], [2]. Despite international efforts, the goals set forth in the United Nations 2030 Agenda for Sustainable Development [3], have not been fully achieved [4], highlighting the need to intensify actions through investment, technological innovation, and international cooperation. In this context, NASA's Gravity Recovery and Climate Experiment (GRACE[1]) and GRACE Follow-On (GRACE-FO[2]) missions have made it possible to monitor for more than two decades variations in terrestrial water storage (TWS), considered a key indicator of freshwater availability, according to the study presented in [5]. In that study, Mexico is classified as a mega-drought region, with a decrease of -0.66 ± 0.05 $cm\ year^{-1}$ in TWS. This is consistent with recent reports from the National Water Commission (2023), which also projects that, by 2030, 78.3% of the population will live in urban areas [6], increasing water stress in various regions; in particular, the Valley of Mexico faces scenarios of absolute scarcity and stress levels exceeding 100% [7]; It also identifies unequal access to drinking water and sanitation services as public issues. The most significant challenges identified in [8] are: climate change, water pollution, water scarcity, poor water management, a lack of resources for research and technological development, and a lack of environmental planning. One infrastructure challenge is highlighted in [9], which presents a study on perceptions of water quality in the Valley of Mexico and finds that families prefer alternative sources of drinking water over city services. The study also finds that families prefer to pay for bottled water because they do not trust the city's services. Globally, UNESCO reports a sustained increase in water consumption (approximately $\sim 1\%$ annually), a trend that will continue through 2050 [10].

In response to this issue, various studies have explored the use of different technologies to understand how the population interacts with water resources and to mitigate the effects of this interaction in urban environments [11]. Monitoring systems have been developed to measure variables such as water quality, pH, temperature, and water level using different types of sensors, including applications in tube wells [12], level and flow measurements in streams using radar [13], and quality and distribution monitoring in industrial settings [14], as well as in [15], where a method is proposed to measure water level using a visual marker and deep learning models. With regard to systems designed for urban areas, in [16], the authors propose an infrastructure system for measuring water consumption as a cost-effective solution, using an ESP32. Likewise, in the mining sector, IoT systems based on wireless multisensor networks have been proposed to enable real-time monitoring of water quality and quantity, overcoming the limitations of cabling [17]. Complementarily, studies such as [18] promote the use of low-cost sensors, highlighting the importance of their calibration to ensure accurate measurements, as well as the need for robust connectivity to maintain data quality and enable subsequent analyses, such as water-level prediction [19].

Other studies focus more on water quality, such as [20], which monitors water turbulence, temperature, and conductivity; it also incorporates a fluorescence sensor to detect the possible presence of thermotolerant coliforms. [21] reports a multi-sensor system embedded within pipes to determine drinking water quality; it uses an optical sensor to measure turbulence and measures the water's electrical conductivity, oxidation-reduction potential, and pH. In the article [22], they measure water temperature to determine whether it is within the appropriate range for fish in the Amazon region (25° to

The associate editor coordinating the review of this manuscript and approving it for publication was Guadalupe Dorantes-Mendez (*Corresponding author: Pedro Miranda-Romagnoli).*

A. M. Fernández-Saldaña, A. Monroy-Avelino, Pedro Miranda-Romagnoli, and R. Noriega-Papaqui are with the Autonomous University of the State of Hidalgo, Pachuca, Hidalgo, Mexico (e-mails: fe244793@uaeh.edu.mx, mo276330@uaeh.edu.mx, pmiranda@uaeh.edu.mx, and rnoriega@uaeh.edu.mx).

[1]https://science.nasa.gov/mission/grace/

[2]https://gracefo.jpl.nasa.gov/

30°); to do this, in addition to temperature sensors, they use a pH sensor and a conductivity sensor to determine the presence of minerals, and they also measure the dissolved oxygen in the water.

The use of low-cost sensors addresses the need for accessible, scalable monitoring systems across diverse environments, overcoming the economic limitations of traditional solutions [23]. Through calibration and experimental validation, it is possible to ensure measurement quality, establishing these technologies as a flexible and efficient alternative for water consumption management [24], [20], [25]. In this respect, low-cost environmental monitoring systems require the integration of key components; according to [26], these systems comprise sensors, power supply and autonomy, communication technology, additional functions, interaction, platform, and microcontrollers.

Despite these advances, most research focuses on large-scale applications, with limited attention paid to residential monitoring. This gap is particularly relevant in Mexico, where the use of tinacos [3] is common due to deficiencies in water management. In this scenario, end users lack accessible tools to manage their water usage; therefore, we propose a low-cost IoT system for real-time monitoring of water levels and consumption in residential settings, aimed at promoting more efficient water use.

The main contributions of this work are: i) the design and implementation of a low-cost IoT system for real-time monitoring of water levels and consumption in residential environments; ii) the integration of flow and level sensors within a modular architecture with cloud connectivity; iii) the experimental validation of the sensors to ensure the reliability of measurements under real-world conditions; and iv) the development of a user interface that enables the visualization and analysis of water consumption. Although the sample size is small, the results are promising: users gave the system a positive evaluation and reported improvements in their water consumption habits.

The rest of the paper is organized as follows: Section II presents a compilation of academic and commercial water monitoring systems, Section III describes the methodology and system architecture; Section IV presents the experimental results; and finally, Section V presents the conclusions and future work.

II. Related Work

This section compiles academic studies on monitoring systems—whether for water levels or consumption—as well as commercial solutions that measure these quantities. Table I has eight column headers: the first indicates the study being reviewed, and the following seven columns indicate the variable of interest being monitored, the type of sensor used, how they communicate, whether there is a calibration process, use of the cloud or a data management platform, field validation, and approximate cost.

The review identified some very interesting studies on water level and consumption, although there appears to be a stronger trend toward water level monitoring. In this area, studies such as [12] focus on water-level monitoring in tubular wells using a piezoelectric sensor. However, although it was field-tested, it offers limited characterization of communication failures and an evaluation focused primarily on cloud architecture. In this vein, [19] focuses on measuring water levels in storm drains at the municipal level using an AxSensor to predict future flooding through computational algorithms. This sensor transmits data every 10 minutes, and if the connection is lost, all data is lost as well, which poses several challenges associated with obtaining reliable data for the research objective.

On the other hand, [29] reports that HC-SR04 measurements were affected as water approached the sensor due to turbulence; the error increased to over 81% of capacity, and the system continued to rely on the Internet for remote interaction and lacked long-term field validation. In [15], an alternative method for measuring water levels using a camera and visual markers is presented. However, its performance depends on visibility and environmental conditions, and it was evaluated only experimentally for flood and watercourse monitoring; therefore, it does not yet outline the steps required for actual implementation, unlike the proposed work, which has been implemented as a complete and functional system.

Regarding studies on water consumption monitoring, [27] measures water consumption using a YF-S201 sensor; however, this study only presents a proof-of-concept evaluation. In this study, the authors ruled out this type of sensor because it does not meet the requirements for long-term validation. In contrast, [28] monitors water consumption in three industrial kitchens in Portugal using a high-cost TUF2000M sensor; however, they report that modifications to the piping infrastructure are required, which could further increase costs. In [16], the AquOculus system is proposed, which measures water consumption/volume consumed using a conventional water meter and an optoelectronic pulse counter, with a focus on urban areas. However, the authors report that the prototype was susceptible to interference from sunlight and required precise installation. In contrast, the proposed system does not require precise installation, making the task easier for the user. A study that measures flow and water level variables is presented in [14], where the authors explore a solution for obtaining information on various water variables using an HC-SR04 for level and a YF-S201 for flow (no consumption). Although they mention field tests of the prototype, one proposed future step is to implement the system in residential settings for a long-term trial, even though this study already presents long-term tests conducted in residential settings.

As for commercial systems for residential use, there are at least three on the market that use architectures similar to the one proposed, but are focused on a single variable. The Rotoplas system uses an ultrasonic sensor to measure the water level, but its installation may require a compatible Rotoplas water tank. Another water level system is Master's, which uses electrodes at four points to monitor water level. The third commercial system for measuring water consumption is Restmo. This system focuses on landscaping water consumption and promises accurate readings, although it does not report device calibration. It also runs on alkaline batteries, and because

[3]In Latin America, a tinaco refers to a rooftop water tank.

TABLE I
WATER MONITORING SYSTEMS REPORTED IN THE LITERATURE AND COMMERCIAL SECTOR

Work	Monitored variables	Sensor	Communication	Calibration	Cloud/Data platform	Field Validation	Approx. Cost
Ray & Goswami (2020) [27]	Water consumption	YF-S201	Wi-Fi via ESP8266	Not reported	ThingSpeak	Functional prototype	Not reported; described as low-cost
Da Silva Júnior et al. (2021) [12]	Water level + others	Piezoelectric level sensor + others	3G; MQTT	Not reported	Google IoT Core; serverless architecture	Yes. Real tubular-well deployment + simulated scalability tests	Not reported; described as low-cost
Pereira et al. (2021), FIK-Water [28]	Flow rate and cumulative consumption	TUF2000M	Modbus with Raspberry Pi	No independent calibration	Bespoke platform	Yes. In three kitchens	Not reported
Olisa et al. (2021) [29]	Water level	HC-SR04 ultrasonic sensor	Wi-Fi via ESP32	Factory calibration	Google Firebase	Functional prototype	Not reported; described as low-cost
Domingues Filho et al. (2024) [15]	Water level	Camera and patterned visual marker	Not reported	Not reported	Not reported	Experimental/image-based evaluation; field deployment not reported	Not reported
Frisk & Johansson (2024) [19]	Water level	AxSensor	LoRaWAN	Not reported	Kristianstad Municipality's IoT Portal	Yes. Municipallity-scale tested.	Not reported
Benhaoua et al. (2025), SW3T-IoT [14]	Water level, flow + others	HC-SR04, YF-S201 + others	NRF24L01; LoRa SX1278 Ra-02	Calibration referenced to previous work	MongoDB; ThingsBoard cloud	Field tests in building environments for transmissions	Not reported
Figueiredo & de Souza Oliveira (2026), AquOculus [16]	Water consumption/consumed volume	Conventional water meter + optoelectronic pulse counter (TIL32 + TIL78)	Wi-Fi via ESP32	Yes. Calibration details not provided	Remote application on Windows Forms	Prototype validation	≈ USD 16
Rotoplas SNUL500-01 [30]	Water level	Ultrasonic	Wi-Fi	Manufacturer calibration	Mobile app	Commercial	≈ USD 70
Master IoT-Water[31]	Water level	Electrodes	Wi-Fi	Not reported	Mobile app	Commercial	≈ USD 70
Restmo [32]	Water consumption	Hall effect sensor	Wi-Fi + Bluetooth	Not reported	Smart Life	Not reported	≈ USD 74
Fernández-Saldaña et al. (This work)	**Water level, water flow, cumulative water consumption**	**Differential-pressure-based level measurement using MPX4250AP sensors + YF-B5 Hall-effect flow sensor**	**Wi-Fi via ESP32**	**Independent experimental calibration of both level and flow sensors using reference measurements and linear fitting**	**Blynk IoT cloud + mobile app; local LCD display**	**Three urban residences with 1,100-L rooftop tanks for 59 days approx; technical, communication and user evaluation**	**≈ USD 85**

the sensor and the electronics that communicate with the app are housed in the same device, sensitive components are exposed to the elements. In contrast, the proposed system offers comprehensive monitoring of the entire residence, calibration processes for accurate measurements of the variables it tracks, direct power supply, a robust and easy-to-install system that shields the connection module from inclement weather, and a user-friendly app where the consumption and water level can be monitored and the data stored for up to one month.

With respect to costs, for academic studies, the values reported correspond to the publication year and may therefore differ from current costs due to inflation. For commercially available solutions, all systems considered focus on measuring a single variable; thus, simultaneous monitoring of water level and consumption requires integrating at least two systems. Although the proposed system has a slightly higher implementation cost, it includes the complete system with two measurement variables.

Unlike academic and commercial systems, this proposal involves the simultaneous monitoring of water level and consumption by integrating a pressure sensor and a flow sensor, respectively. Related to level monitoring, most proposals use ultrasonic sensors, which can be somewhat inaccurate in real-world applications. Similarly, regarding the flow sensor, some authors report using the YF-S201 sensor without validating its use outside the laboratory [27], [14]; for this reason, this study uses a YF-B5 with a metal housing, which is better suited for outdoor applications. It should be noted that both sensors underwent calibration processes, which are reported in detail. It is worth noting that this proposal includes the storage of historical water level and consumption data for a period of up to one month, as well as real-time flow rate readings. To

experimentally validate the feasibility of the proposed system, three complete systems were deployed in three residential settings over a period of approximately 59 days.

III. Methodology

The water monitoring system was developed using a comprehensive approach, as described in [26]. Fig. 1 illustrates the methodology followed in this research. In the first phase (Design), the overall architecture of the system was defined using a modular approach, which includes data acquisition, processing, transmission, and presentation. Based on this definition, the physical quantities of interest—in this case, water level and flow—were established, and the corresponding sensors were selected, taking into account criteria such as operating range, stability, electronic compatibility, and suitability for domestic environments. Based on these decisions, a connection module was designed and built to house the system's electronics. This module includes a regulated power supply, enabling continuous operation with low energy consumption. Once the prototype hardware was tested and found to function correctly, the communication and data visualization interface was developed.

In the second phase (Calibration), both sensors were calibrated independently through controlled experiments that simulated real-world operating conditions. The data obtained were compared with reference values and fitted to linear models to determine calibration constants, thereby reducing systematic errors. Between the first phase and this one, the connection is bidirectional because sensor calibration is closely tied to the system design, given how the sensors are implemented.

For the third module (System implementation), data acquisition was performed using an ESP32-WROOM-32 microcontroller, which is specifically oriented for IoT applications. Its key features include native Wi-Fi connectivity, compatibility with various sensors, low power consumption, the ability to process, filter, and transmit data, and compliance with the IEEE 802.11 standard [33]. The Blynk platform was used as the cloud interface and mobile app due to its compatibility with various communication protocols and its direct integration with ESP32 devices. If this block works as intended, proceed directly to the next one; otherwise, return to the design and make the necessary modifications. There is no need to go back through the second block; once it has been modified, proceed directly to the last block.

Regarding the final phase (Validation), the system was installed in three residences located in urban areas; this phase was divided into three stages. During the first stage, data was collected to establish a baseline for energy consumption; subsequently, user interaction with the system was enabled through a mobile app. Finally, the system was evaluated on its technical performance and user perception through a survey. At the end of this block, changes related to the first block may arise, since once the user interacts with the system, they will provide feedback on how to improve it. Once the feedback has been addressed, return to the current block, complete the process, and obtain the final product.

A. Electronic design of the connection module

The electronic design of the connection module (see Fig. 2) is organized into four main functional blocks: power supply, processing unit (microcontroller), measurement interface (Sensors), and display interface. The power supply system is based on an LM7805 linear regulator, which generates a regulated 5 V from an external DC source, incorporating a main power switch and decoupling capacitors to ensure a stable power supply. The processing unit is implemented using an ESP32 DevKit V1 module based on the ESP32-WROOM-32, which is responsible for data acquisition, local data processing, and management of communication interfaces.

As for the water flow meter, the sensor was selected based on the characteristics of the installation site. Since the device would be installed at the outlet of the water tank, the connection diameter had to be 1 or 3/4 inch to avoid a significant reduction in the home's water supply pressure. Based on this criterion, sensors such as the Adafruit and the DK-FS-001—both with a 1/2-inch connection diameter—were discarded, as were other 1/4-inch alternatives. In contrast, the YF-S201 model, with a 1-inch diameter, was experimentally evaluated in the laboratory; however, it was ruled out because its calibration constant varied across devices. Furthermore, its plastic body could limit performance in outdoor installations. The most robust version, made of bronze and with a calibration constant that remained consistent across devices, was the YF-B5 in 3/4-inch. The YF-B5 output signal is an analog pulse that is connected to an ADC input on the microcontroller.

Similarly, various options for level measurement were evaluated, with the DFRobot KIT0139 standing out; however, it failed due to temperature variations when tested at extreme conditions. Finally, water level measurement was performed using a residential adaptation of the MPX4250AP pressure sensor [34], which requires a 5V power supply voltage with ground and signal connections [35]; the analog signal is acquired directly by one of the ESP32's ADC inputs. To facilitate installation and sensor replacement, and to improve the system's mechanical robustness in the field, the sensors are connected to the microcontroller via XLR connectors.

The connection module was built on a two-piece enclosure measuring $6.22 \times 3.54 \times 2.36$ inches. Fig. 3a shows all the components mounted on the base of the enclosure. The female XLR connectors were assembled and the reset button and power supply were also installed. Fig. 3b shows how the switches were mounted on the box lid: a rocker switch turns the module on and off, three toggle switches control power for the I2C LCD display, Wi-Fi, and the RGB LED that indicates the module's Wi-Fi connection status, as well as a push-button switch to toggle the reading mode on the LCD screen between the two sensors. Although one of the system's objectives was to display the information in a mobile app, an LCD screen is crucial for viewing the readings directly on the module and thus verifying that the information transmitted to the mobile phone is correct. The electronic schematic is provided in the "Diagram" folder of the GitHub repository: https://github.com/pmirandar/IEEELAT_LC_WM.

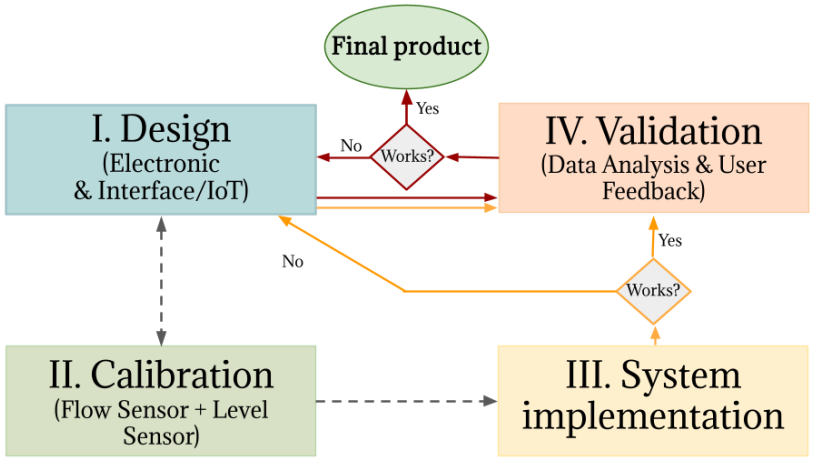


Fig. 1. Methodology in this research study for the design, calibration, implementation, and experimental validation of the proposed system.

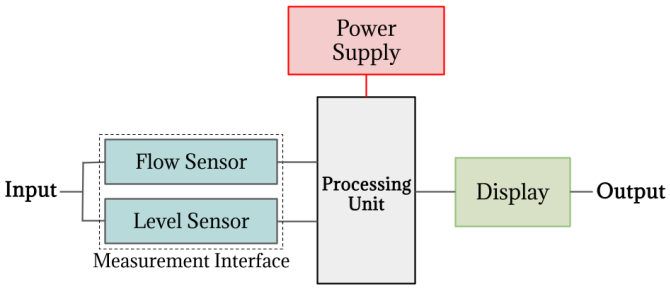


Fig. 2. Simplified block diagram of the proposed connection module design, showing the integration of the sensors, the data acquisition and processing unit, and the display that shows the measurement results.

1) Cost: Regarding the cost of the system, the goal is to keep it affordable, durable as well as user-friendly. Table II below lists the materials needed to build the system, along with approximate costs in dollars.

TABLE II
COST OF THE SYSTEM COMPONENTS

Component	Quantity	Total Cost (USD)
Cable	20 m	5.88
Pressure sensors	2	41.18
XLR male connectors	2	2.13
XLR chasis	2	6.00
ESP32	1	7.34
I2C LCD display	1	3.08
Flow sensor	1	6.00
Enclosure	1	11.76
Other components	1	1.88
TOTAL		85.25

Note: The costs were established on September 4, 2026, in Mexico, using an exchange rate of 1 USD = 16.89 MXN.

B. User Interface

The Blynk IoT platform was used to display real-time data, leveraging official ESP32 libraries to transmit and synchronize it over Wi-Fi. A graphical interface for a mobile app was designed on this platform, allowing users to view the tank fill percentage at the device's location and the history of measured water levels. Additionally, the app displays real-time water consumption and a historical record of cumulative consumption.

The Blynk platform serves as cloud storage, allowing data generated by the system to be downloaded later for offline analysis and processing. Due to the data storage limitations of the basic paid version, a strategy was implemented to optimize data transmission. Specifically, the system was programmed to calculate the average of water level measurements and transmit that value to the cloud once per minute. However, for water consumption monitoring, data transmission was dependent on flow detection, so that information was transmitted only when actual consumption occurred, and the corresponding sensor was activated.

C. Sensors Calibration

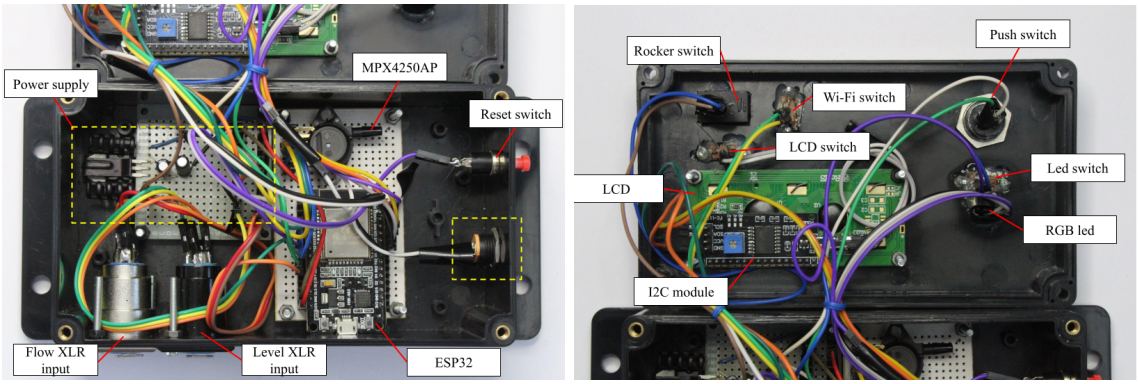
This subsection describes the procedure for calibrating both the water-flow sensor and the water-level sensor.

1) Flow Sensor Calibration: The YF-B5 sensor, a highly weather-resistant electromechanical sensor, was selected to monitor the flow rate. This sensor uses the Hall effect to measure the number of pulses generated as the fluid passes through it [36]. To calibrate the sensor and display this information in liters, the following formula is applied:

$$L_m = \frac{(N/C_f)t^{-1}}{C_c}, \tag{1}$$

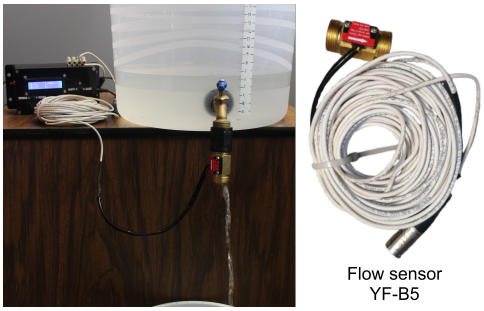
where L_m is the measured volume in liters, N is the number of pulses the sensor outputs per second, t is the time equivalent to one minute in seconds, $C_f = 6.6$ is the sensor constant provided by the manufacturer, and C_c is the calibration constant obtained in this process.

To calibrate the sensor, a measurement prototype was built using a 40-liter tank marked in 1-liter increments. A hole was drilled in the bottom of the tank wall, and a valve was installed for the water outlet; the sensor was then positioned in accordance with the flow direction and connected to the microcontroller, as shown in 4a.

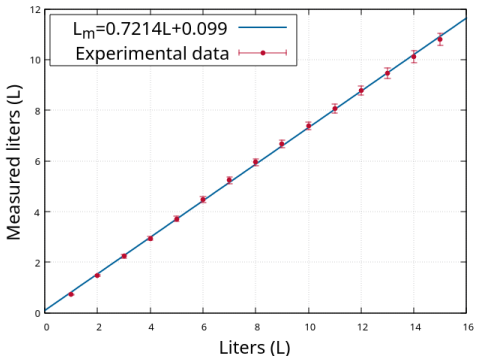


(a) (b)

Fig. 3. Construction and physical assembly of the connection module. (a) Bottom view, showing the sensors, processing unit, and power supply connections. (b) Top view, showing the display and user control buttons.

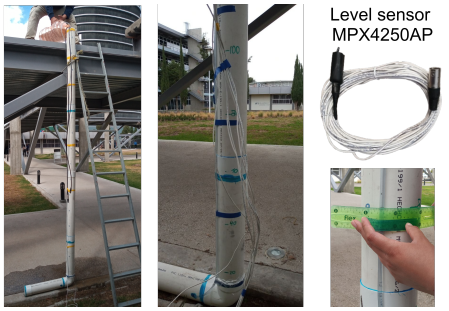


(a)

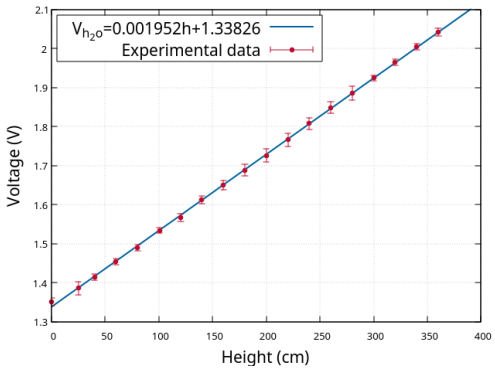


(b)

Fig. 4. (a) Prototype developed for calibrating the YF-B5 sensor. (b) Linear fit of the sensor response with $V_{cc} = 5V$.



(a)



(b)

Fig. 5. (a) Prototype developed for calibrating the MPX4250AP sensor. (b) Linear fit for the pressure sensor with $V_{air} = 1.3V$ and $V_{cc} = 5V$.

Once the prototype was installed, five tests were conducted for each sensor using at least 15 liters, beginning with the maximum capacity of the container. In Fig. 4b a linear fit is presented, based on data collected, yielding the equation $L_m = C_c L + b$, where $C_c = 0.7214 \pm 0.00422$ and the y-intercept $b = 0.099 \pm 0.03837$, from which it follows that $C_c = 0.7214$. This value is substituted into (1) to obtain the correct measurements. After the sensor was installed at the test site, the experiment was performed in reverse, filling the graduated tank downstream of the sensor to verify the calibration.

2) Pressure Sensor Calibration: To calibrate the MPX4250AP pressure sensor, it is necessary to establish a relationship between the sensor voltage and the water level in the tank. The pressure in a water column can be calculated using the following formula:

$$P_{h_2o} = P_0 + \rho_{h_2o} g h, \tag{2}$$

where P_0 is the atmospheric pressure, ρ_{h_2o} is the density of water ($997 kg/m^3$ at 20°C), and g is the value of the acceleration due to gravity at a given height, approximately

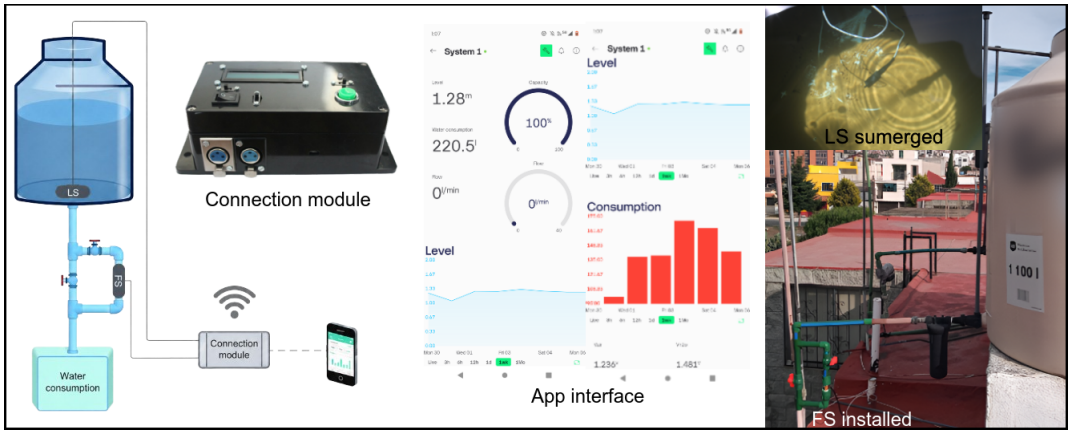


Fig. 6. Monitoring system implementation using IoT. The left panel shows the implementation workflow, the center panel presents the connection module and app interface, and the right panel illustrates the actual system implementation (LS: level sensor; FS: flow sensor).

$9.78\ m/s^2$ in Pachuca, located north of the Valley of Mexico, Mexico. Therefore, the height in meters will be given by:

$$h = \frac{P_{h_2o} - P_0}{\rho_{h_2o} g} \quad . \tag{3}$$

On the other hand, the manufacturer of the MPX4250AP pressure sensor provides the following specifications [34]:

$$V_{out} = V_{cc}(P \cdot 0.004 - 0.04) \pm Error, \tag{4}$$

where P is the pressure in kPa, V_{cc} is the supply voltage, 0.004 and 0.04 are constants, and V_{out} is the voltage output by the sensor. If the $Error$ is neglected and solve for the pressure in equation (4), it follows,

$$P = \left\{ \frac{V_{out}}{V_{cc}} + 0.04 \right\} / 0.004 \quad . \tag{5}$$

Now, the difference between the pressures P_{h_2o} and P_{air} can be calculated for substitution into equation (3), and by replacing V_{out} with V_{h_2o}, the following is obtained:

$$h = \frac{(V_{h_2o} - V_{air})}{V_{cc} \cdot 0.004 \cdot \rho g} \quad . \tag{6}$$

If $M = 1/(0.004 \cdot \rho g)$, equation (6) becomes:

$$h = \frac{(V_{h_2o} - V_{air}) \cdot M}{V_{cc}} \quad , \tag{7}$$

where $M = 25.602$ at the altitude of Pachuca, noting that P in equation (4) is in kPa.

To verify this theoretical result, the value of M will now be determined experimentally. To do this, a prototype was designed to simulate the height of the water tank. It consists of an approximately 3.6 m tall L-shaped pipe, sealed at one end and connected to a transparent hose at its base. This setup reproduces the pressure exerted by water on the sensor inside a water tank of at least this height; see Fig. 5a. In each test, the water level is varied by 20 centimeters; then the required voltage is applied to the sensor and a reading is taken with the multimeter at the output signal pin.

The measurements obtained from the calibration tests were compiled and fitted to a linear model (see Fig. 5b), resulting in the equation $V_{h_2o} = mh + V_{air}$ where $m = 0.001952 \pm 8.7 \times 10^{-6}$ and the y-intercept $V_{air} = 1.33826 \pm 0.001836$. Therefore, to obtain the water level value, once the sensor has been calibrated, it can be use the equation:

$$h = \frac{(V_{h_2o} - V_{air})}{m} = (V_{h_2o} - V_{air}) \cdot 512.295\ [cm] \quad . \tag{8}$$

If the equation (8) is expressed in terms of the voltage supply V_{cc}, which in this case was $5V$, then it follows that,

$$h = \frac{(V_{h_2o} - V_{air})}{V_{cc}} \cdot 25.615\ [m] \quad . \tag{9}$$

That is, $M = 25.615$, which is not very different from the theoretical value previously found. It is also worth noting that equation (9) accounts for the actual voltage supply value, since it can vary slightly in many cases.

IV. Results

The monitoring system was installed in three urban residences, each equipped with its own level sensor, flow sensor, and connection module, and the app was shared with users. It should be noted that each home has different conditions; that is, there is variation in the number of people living there and the distances between the devices.

A. System Implementation

The monitoring system is designed for residential use in urban areas. To install the complete system, the level sensor is first submerged in the water tank, while the flow sensor is placed at the outlet of the same tank. All test installations were conducted in 1,100-liter water tanks. Fig. 6 shows a diagram of the complete installation, where the abbreviations “LS” and “FS” stand for the level sensor and the flow sensor, respectively; the gray lines represent the wiring; the blue lines represent the pipe; and the dotted line represents the Wi-Fi connection.

The flow sensor was installed at the outlet of the water tank rather than the inlet because the water supply to homes often has variable pressure, which may fall outside the sensor’s measurement range. The water flow is redirected toward the sensor by adjusting the shut-off valves. Installing the level

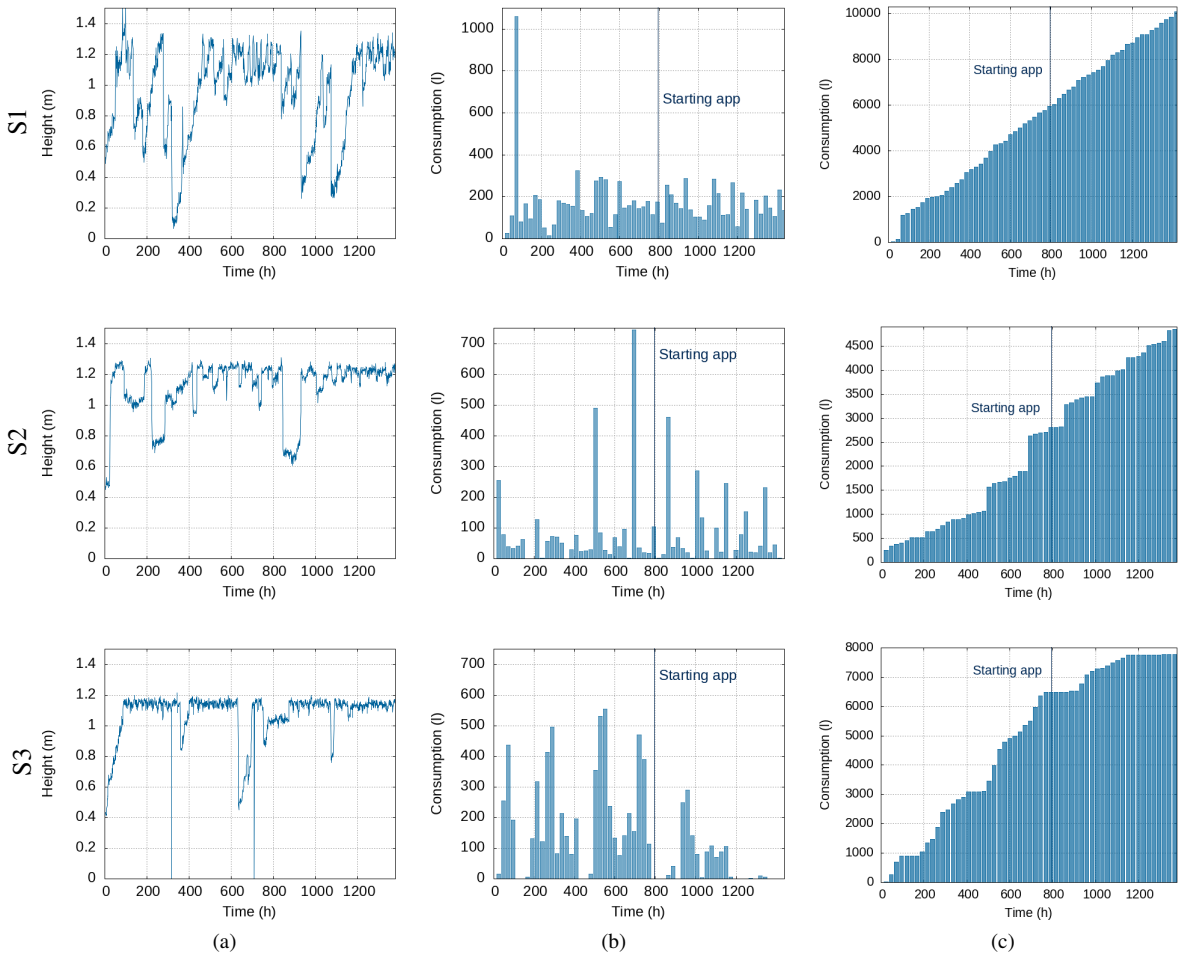


Fig. 7. Water level, daily consumption, and accumulated consumption during the test period for three systems. (a) Water level. (b) Water consumption per day. (c) Accumulated water consumption.

sensor was much simpler, as the sensor's design makes the task easier; it was simply submerged in the tank.

The connection module was placed in a location inside the residence with a Wi-Fi signal. The sensor cables were run along the perimeter of the property until they reached the module, where they were connected, and the connection to the smartphone app was established.

B. System Validation: Data Analysis

For validation, a testing period of approximately 59 days was used; the data-taking is summarized in Fig. 7, where row S1 corresponds to data from System 1, S2 to System 2, and S3 to System 3. The column corresponding to Fig. 7a illustrates the temporal changes of the water level for the three installed systems, showing typical filling and consumption cycles. Similarly, Fig. 7b shows consumption for the three properties during the test period; each bar represents one day of consumption. It also indicates the moment when the residents of the properties began using the app. Looking at these graphs, it is interesting to note that in System 1, consumption appears more uniform than in the other homes, while in System 2, consumption patterns are very distinct, with higher consumption occurring once a week. Finally, in System 3, no apparent pattern emerges. The column in Fig. 7c shows cumulative consumption, demonstrating variability across days and reflecting user behavior. Table III summarizes the observed reduction and consumption data for the three systems.

TABLE III
AVERAGE WATER RESIDENCE CONSUMPTION PER DAY

System	Consumption Period 1 (liters/day)	Consumption Period 2 (liters/day)	Observed reduction (%)
1	180.4	158.7	12.0
2	85.1	80.2	5.7
3*	196.3	85.0	56.7

Note: *The data from the last 10 days were excluded from the analysis.

Regarding System 1, Fig. 7a-S1 shows that the property experiences long periods without water supply from the municipal water provider. Furthermore, on some occasions when there is a supply, the tank does not fill up completely; at least during the test period, four significant intervals can be seen where water was scarce. On the other hand, in Fig. 7b-S1, it can be seen that consumption in this house remained relatively

steady. Before using the app, the average was 180.4 liters per day; after using the app, it was 158.7 liters per day. Total consumption is approximately 10,079.6 liters, equivalent to 9.1 water tanks, with a 12% observed reduction. Meanwhile, in Fig. 7c-S1, the cumulative total shows steady growth with a downward trend.

For System 2, Fig. 7a-S2 shows less dramatic fluctuations, but these still highlight weaknesses in the supply system, such as the period between approximately 200 and 400 hours, when it took a little over a week to fully fill the tank. Fig. 7b-S2 shows a weekly pattern of higher consumption; in total, approximately 4,893.7 liters were consumed, equivalent to 4.4 water tanks, resulting in a 5.7% observed reduction. Before using the app, they consumed an average of 85.1 liters per day; after using the app, the average daily consumption was 80.2 liters. Finally, Fig. 7c-S2 shows a stepwise increase with a slightly downward trend.

For System 3, Fig. 7a-S3 shows a more efficient and consistent water supply, with significantly fewer shortages compared to S1 and S2. Fig. 7b-S3 is interesting because unlike Systems S1 and S2, it shows both short and long periods without water consumption and lower daily consumption after the app was enabled. This is due to the homeowner frequently travels between states; furthermore, the second half of the test period coincided with business trips, and increased work activity kept the homeowner away from home more than usual. Additionally, the near-zero consumption toward the end of the recording period coincided with a ten-day absence. Thus, these days, beginning at approximately 1,176 hours, were excluded from the before-and-after comparison. Fig. 7c-S3 shows a cumulative recorded consumption of approximately 7,752.9 liters, equivalent to 7.0 water tanks on average. After excluding the absence period, average daily consumption was 196.3 liters before app access and 85.0 liters afterward, corresponding to an observed reduction of 56.7%. Still, this percentage is atypical compared to those obtained from the other two systems; therefore, variations in the household context may have influenced consumption; consequently, the reduction cannot be attributed exclusively to the use of the app in this case.

C. System Validation: Communication Performance

During the evaluation period, the three monitoring systems exhibited different connectivity and reliability patterns, as summarized in Table IV and Fig. 8. The metrics analyzed include total online time (T_{on}), total offline time (T_{off}), availability, the number of failures and recoveries, mean time between failures (MTBF), mean time to recovery (MTTR), as well as the maximum and average durations of the online and offline states.

System 1 logged 1,369.63 h of online operation and 16.68 h of offline operation, achieving an availability of 98.80%. This generally stable performance was tempered by 135 failure and recovery events, which lowered the MTBF to 10.15 h and indicate frequent, short-duration interruptions. However, the mean recovery time was only 0.12 h, showing that most failures were corrected quickly and limiting the impact of these interruptions. The maximum offline interval observed for S1 was 7.99 h.

TABLE IV
AVAILABILITY AND RELIABILITY STATISTICS FOR THE THREE SYSTEMS

Metric	S1	S2	S3
T_{tot} (days)	59	59	59
T_{on} (h)	1369.63	1335.17	1392.09
T_{off} (h)	16.68	54.90	1.96
Avail. (%)	98.80	96.05	99.86
Fails	135	13	33
Recovs.	135	13	33
MTBF (h)	10.15	102.71	42.18
MTTR (h)	0.12	4.22	0.06
Max ON (h)	166.31	253.46	447.46
Max OFF (h)	7.99	16.02	0.55
Mean ON (h)	10.15	102.71	40.94
Mean OFF (h)	0.12	4.22	0.06

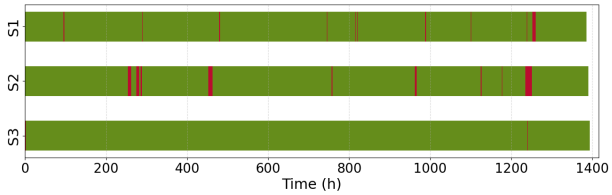


Fig. 8. System connectivity status over time (green: online and transmitting data; red: offline and unable to transmit data).

System 2 had the lowest availability among the evaluated systems, at 96.05%. Its node remained online for 1,335.17 h and offline for 54.90 h. With only 13 failure events, System 2 experienced longer outages, reflected in an MTTR of 4.22 h. Its MTBF reached 102.71 h, indicating that failures occurred less frequently, though with greater operational impact. This pattern is consistent with relatively stable operation interrupted by prolonged outages.

Finally, System 3 demonstrated the best overall performance, with 99.86% availability, 1,392.09 h of online operation, and only 1.96 cumulative offline hours. Although 33 failure events were detected, the associated recovery time remained very short, with an MTTR of 0.06 hours. Furthermore, S3 had the longest maximum continuous online interval (447.46 h), indicating highly stable communication performance over extended periods. The short offline duration and rapid recovery capability suggest that S3 provides the most robust and reliable operation among the evaluated systems.

System disconnections from the cloud cause the loss of instantaneous water consumption readings, but not the accumulated consumption value, which is stored in the ESP32's local memory and sent to the cloud as soon as the connection is restored. Therefore, even if instantaneous consumption records are lost during a connection outage, the integrity of the cumulative consumption is maintained. Additionally, the user always has access to real-time data via the LCD screen, even if the connection is lost.

D. System Validation: User Feedback and Usability Assessment

As part of system validation, a survey was administered via Google Forms to six residents of the houses where the mon-

TABLE V
SURVEY COMPLETED BY SYSTEM USERS

Section	Question	Level of satisfaction 100%	75%	50%	25%
I	The mobile application (app) is easy to use.	5	1	0	0
	The app interface is user-friendly.	5	1	0	0
	The information within the app is presented clearly and in an organized manner.	5	1	0	0
	It was easy to learn how to use the system.	3	3	0	0
II	The data presented both in the connection module and in the app are clear.	4	2	0	0
	The information regarding water consumption is useful.	6	0	0	0
	The information regarding water level is accurate.	5	1	0	0
	I trust the data provided by the system.	6	0	0	0
III	The system operates stably.	5	1	0	0
	Data updates are timely, so they are displayed in real time.	5	1	0	0
	I did not experience failures during use.	4	2	0	0
IV	The system helped me become more aware of my water consumption.	5	1	0	0
	I changed some of my water consumption habits.	4	2	0	0
	I believe the system contributes to water savings.	3	3	0	0
V	I am satisfied with the system.	6	0	0	0
	I would recommend the monitoring system to others.	5	1	0	0
	I consider it useful to implement this system in homes.	6	0	0	0
VI	User feedback				
VII	General information				

itoring systems were installed. The survey was divided into seven sections: the first five were used to rate the performance and usability of the system, using a four-level scale where the lowest corresponds to ”disagree” (25%), next was ”neutral” (50%), ”agree” (75%), and finally ”totally agree” (100%). The sixth section collected feedback in the form of user comments, and the seventh contained general information (see Table V).

Of the first five sections, the first evaluates the system's usability, which received a score of 93.8%, with questions about how easy it is for users to navigate the system's components. In the second section, regarding the quality of the information presented by the system, a score of 96.8% was obtained, with questions such as how clear the presented data is, whether the flow sensor information regarding consumption is useful, and how accurate the water level information is. In the third section on system performance, a score of 94.4% was obtained, with stability, real-time data updates, and failures during use reviewed. For the fourth section, self-reported impact on user behavior, a score of 91.6% was obtained; users were asked whether the system helped them become more aware of their consumption, whether they changed any habits, and whether it contributed to water savings. In the final section of questions by score, general opinions about the system were solicited, such as how satisfied the user is with the system, whether they would recommend it, and whether they consider its implementation in more homes to be useful; this section yielded a score of 98.6%. This resulted in an overall percentage of 95.1%.

In Section Six, respondents are asked open-ended questions to gather feedback on the entire system. When asked what they liked most about the system, users mentioned the availability of real-time and historical data, the app's ease of use, and how it helped them adopt saving strategies for better consumption planning. As for areas for improvement, some users believe that alerts for low water levels or leaks should be added, as well as a larger LCD screen; in general, the recommendations focus on expanding the system's functions rather than correcting deficiencies. As additional comments, the users self-reported there was a high level of acceptance of the system as a useful tool for promoting more informed and efficient water management.

Finally, Section 7, on general information, focused on data from three residences, where 83.3% of users reported using the app daily, while 16.7% used it two to three times a week. Regarding local information viewing, 50% reported daily screen use, 16.7% every other day, 16.7% infrequently, and 16.7% never.

Although these results should be interpreted with caution due to the limited number of households, preliminary evidence of a reduction in water consumption was observed following the installation of the app.

V. CONCLUSIONS AND FUTURE WORK

In light of current challenges related to water availability, efforts have been made to develop technological solutions to improve water management. The developed system underwent calibration and experimental validation, improving measurement accuracy and demonstrating that low-cost sensors are a viable alternative for domestic applications when implemented in accordance with appropriate measurement criteria. Furthermore, the systems demonstrated high connectivity availability—over 95% in all cases—ensuring access to real-time information and providing users with a continuous view of their water consumption and water level.

A reduction in water consumption was observed in all participating households, with decreases of 5.7%, 12.0%, and

56.7%, respectively. The reduction observed in the third household was considerably greater than in the other two; however, this should not necessarily be interpreted as an improvement in water-use efficiency or changes in consumption habits, as it could instead be attributed to occupancy, household activities, vacations, or contextual conditions. Although the general trend is encouraging, it should be considered a preliminary observation and not as evidence of a causal effect of the system on user consumption behavior because the limited number of residences and participants prevents these results from being generalized. Nevertheless, the system demonstrated its ability to record and visualize variations in water consumption across households, including substantial changes that may be better understood when considering contextual factors such as occupancy and household activities.

Furthermore, the self-reported positive feedback on behavior provided by residents supports the system's ease of use and feasibility under real-world residential settings over extended periods. In general, the results show that low-cost IoT systems represent a viable and scalable alternative to domestic water monitoring in urban areas of Mexico, which can help raise awareness of water use and support informed decisions regarding water management.

Future work will focus on expanding the number of case studies and developing a more comprehensive system that incorporates additional sensors for monitoring specific water quality parameters, as well as capabilities to detect potential anomalies such as leaks, spills, and service interruptions. These developments will require expanding software and IoT capabilities to implement an early-warning system, based on the analyses of consumption, capable of identifying anomalous patterns and providing recommendations to users. Additionally, the identification of alternative data management platforms is also considered for future work.

ACKNOWLEDGMENTS

The authors Andrea M. Fernández-Saldaña and Alejandro Monroy-Avelino thank the Secretariat of Science, Humanities, Technology, and Innovation (SECIHTI, formerly CONAHCYT) for financial support through a graduate scholarship. The authors also thank the anonymous reviewers for their valuable comments and constructive suggestions, which helped improve the quality and clarity of this manuscript.

REFERENCES

[1] J. S. Famiglietti and G. Ferguson, "The hidden crisis beneath our feet," *Science*, vol. 372, no. 6540, pp. 344–345, 2021.

[2] B. Scanlon, S. Fakhreddine, A. Rateb *et al.*, "Global water resources and the role of groundwater in a resilient water future," *Nature Reviews Earth & Environment*, vol. 4, no. 6540, pp. 87–101, 2023.

[3] United Nations, "Transforming our World: The 2030 Agenda for Sustainable Development," New York, NY, USA, 2015, (Accessed:2026-02-23). [Online]. Available: https://sdgs.un.org/sites/default/files/publications/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf

[4] United Nations Department of Economic and Social Affairs, "The Sustainable Development Goals Report 2025," New York, NY, USA, 2025, (Accessed:2026-02-23). [Online]. Available: https://unstats.un.org/sdgs/report/2025/The-Sustainable-Development-Goals-Report-2025.pdf

[5] H. A. Chandanpurkar, J. S. Famiglietti, K. Gopalan, D. N. Wiese, Y. Wada, K. Kakinuma, J. T. Reager, and F. Zhang, "Unprecedented continental drying, shrinking freshwater availability, and increasing land contributions to sea level rise," *Science Advances*, vol. 11, no. 30, 2025.

[6] Comisión Nacional del Agua, "Estadísticas del agua en México 2023," México, 2023, (Accessed: 2026-05-28). [Online]. Available: https://sinav30.conagua.gob.mx:8080/port_publicaciones.html

[7] ——, "Numeragua 2022," México, 2022, (Accessed: 2026-04-07). [Online]. Available: https://files.conagua.gob.mx/conagua/publicaciones/Publicaciones/Numeragua%202022.pdf

[8] J. A. M.-N. Lilia Rodríguez-Tapia, Daniel A. Revollo-Fernández, "Household's perception of water quality and willingness to pay for clean water in Mexico City," *Economies*, vol. 5, no. 12, 2017.

[9] M. L. P. Felipe I. Arreguín Cortés and H. M. Mogollón, "Mexico's water challenges for the 21st century," in *Water Resources in Mexico: Scarcity, Degradation, Stress, Conflicts, Management, and Policy*, Úrsula Oswald Spring, Ed. Springer Berlin, Heidelberg, 2011.

[10] United Nations, *The United Nations World Water Development Report 2023: Partnerships and Cooperation for Water*. Paris, France: UNESCO, 2023.

[11] B. R. Rosenzweig, P. Herreros Cantis, Y. Kim, A. Cohn, K. Grove, J. Brock *et al.*, "The value of urban flood modeling," *Earth's Future*, vol. 9, 2021.

[12] A. C. da Silva Júnior, R. Munoz, M. d. l. Á. Quezada, A. V. Lira Neto, M. M. Hassan, and V. H. C. de Albuquerque, "Internet of water things: A remote raw water monitoring and control system," *IEEE Access*, vol. 9, pp. 36 505–36 519, 2021.

[13] S. Catsamas, B. Shi, M. Wang, J. Xiao, P. Kolotelo, and D. McCarthy, "A low-cost radar-based IoT sensor for noncontact measurements of water surface velocity and depth," *Sensors*, vol. 23, no. 14, 2023.

[14] M. K. Benhaoua, A. Dahane, R. Benameur, I. B. Benziane, H. E. Zahaf, A. Benhariga, A. Elouissi, C. Boudia, and S. Souihi, "SW3T-IoT: Smart water monitoring based on a three-tier IoT architecture," *IEEE Access*, vol. 13, pp. 206 331–206 354, 2025.

[15] G. M. Domingues Filho, C. M. Ranieri, S. Neves Matos, R. Ipolito Meneguette, and J. Ueyama, "Deep learning and object detection for water level measurement using patterned visual markers," *IEEE Latin America Transactions*, vol. 22, no. 11, pp. 892–898, 2024.

[16] M. Pilotto Figueiredo and L. de Souza Oliveira, "AquOculus: A cost-effective advanced metering infrastructure for urban water distribution systems," *IEEE Latin America Transactions*, vol. 24, no. 2, pp. 174–186, 2026.

[17] L. Bo, Y. Liu, Z. Zhang, D. Zhu, and Y. Wang, "Research on an online monitoring system for efficient and accurate monitoring of mine water," *IEEE Access*, vol. 10, pp. 18 743–18 756, 2022.

[18] K. Chan, D. N. Schillereff, A. C. Baas, M. A. Chadwick, B. Main, M. Mulligan, F. T. O'Shea, R. Pearce, T. E. L. Smith, A. van Soesbergen, E. Tebbs, and J. Thompson, "Low-cost electronic sensors for environmental research: Pitfalls and opportunities," *Progress in Physical Geography: Earth and Environment*, vol. 45, no. 3, pp. 305–338, 2020.

[19] F. Frisk and O. Johansson, "Comparative evaluation of water level forecasting using IoT sensor data: Hydrodynamic Model SWMM vs. Machine Learning Models Based on NARX Framework," *Water*, vol. 16, no. 19, 2024.

[20] D. B. Krklješ, G. V. Kitić, C. M. Petes, S. S. Birgermajer, J. D. Stanojev, B. M. Bajac, M. N. Panić, V. M. Radonić, I. D. Brčeski, R. M. Štravs, N. N. Janković, and J. B. Matović, "Multiparameter water quality monitoring system for continuous monitoring of fresh waters," *IEEE Sensors Journal*, vol. 24, no. 7, pp. 11 246–11 260, 2024.

[21] T. P. Lambrou, C. C. Anastasiou, C. G. Panayiotou, and M. M. Polycarpou, "A low-cost sensor network for real-time monitoring and contamination detection in drinking water distribution systems," *IEEE Sensors Journal*, vol. 14, no. 8, pp. 2765–2772, 2014.

[22] R. Yauri, M. Rios, and J. Lezama, "Water quality monitoring of Peruvian Amazon based in the Internet of Things," in *2017 IEEE XXIV International Conference on Electronics, Electrical Engineering and Computing (INTERCON)*, 2017, pp. 1–4.

[23] S. H. Abdulhussain, B. M. Mahmmod, A. Alwhelat, D. Shehada, Z. I. Shihab, H. J. Mohammed, T. H. Abdulameer, M. Alsabah, M. H. Fadel, S. K. Ali, G. H. Abbood, Z. A. Asker, and A. Hussain, "A comprehensive review of sensor technologies in IoT: Technical aspects, challenges, and future directions," *Computers*, vol. 14, no. 8, 2025.

[24] F. Leischner, T. Mietzel, N. Gerner, and S. Heldt, "A comparison between low-cost single-parameter IoT sensors and traditional high-cost monitoring stations for stream water quality assessment," *Environmental Technology & Innovation*, vol. 41, p. 104788, 2026.

[25] R. D. Harmel, H. E. Preisendanz, K. W. King, D. Busch, F. Birgand, and D. Sahoo, "A review of data quality and cost considerations for water quality monitoring at the field scale and in small watersheds," *Water*, vol. 15, no. 17, 2023.
[26] P. Hamel, N. Ding, F. Cherqui, Q. Zhu, N. Walcker, J.-L. Bertrand-Krajewski, P. Champrasert, T. D. Fletcher, D. T. McCarthy, O. Navratil, and B. Shi, "Low-cost monitoring systems for urban water management: Lessons from the field," *Water Research X*, vol. 22, p. 100212, 2024.
[27] A. Ray and S. Goswami, "IoT and cloud computing based smart water metering system," in *2020 International Conference on Power Electronics & IoT Applications in Renewable Energy and its Control (PARC)*, 2020, pp. 308–313.
[28] L. Pereira, V. Aguiar, and F. Vasconcelos, "FIKWater: A water consumption dataset from three restaurant kitchens in Portugal," *Data*, vol. 6, no. 3, 2021.
[29] S. C. Olisa, C. N. Asiegbu, J. E. Olisa, B. O. Ekengwu, A. A. Shittu, and M. C. Eze, "Smart two-tank water quality and level detection system via IoT," *Heliyon*, vol. 7, no. 8, 2021.
[30] Grupo Rotoplas S.A.B. de C.V. , "Water Level Meter with Ultrasonic Sensor," 2026, (Accessed: 2026-08-30). [Online]. Available: https://rotoplas.com.mx/product/Medidordeniveldeaguaconsensorultrasnicosolar_312378/
[31] MASTER, "Smart Water Level Sensor," 2025, (Accessed: 2026-09-01). [Online]. Available: https://lix.li/fhfCDC
[32] Restmo Innovations Inc., "Smart Wi-Fi Flow Meter," 2026, (Accessed: 2026-08-30). [Online]. Available: https://restmo.org/
[33] F. Jan, N. Min-Allah, S. Saeed, S. Z. Iqbal, and R. Ahmed, "IoT-based solutions to monitor water level, leakage, and motor control for smart water tanks," *Water*, vol. 14, no. 3, 2022.
[34] NXP Semiconductors, Inc., "MPX4250AP manifold absolute pressure sensor," 2005, (Accessed: 2026-05-19). [Online]. Available: https://www.nxp.com/part/MPX4250AP#/
[35] A. Abeysekara and et al. (HAWC Collaboration), "The High-Altitude Water Cherenkov (HAWC) observatory in México: The primary detector," *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 1052, p. 168253, 2023.
[36] Seeed Studio, "Water flow sensor YF-B5," 2026, (Accessed: 2026-03-09). [Online]. Available: https://www.seeedstudio.com/Water-Flow-Sensor-YF-B5-p-2882.html



Andrea Monserrath Fernández-Saldaña is currently pursuing the Ph.D. degree in Computational Sciences at the Autonomous University of the State of Hidalgo (UAEH), Mexico, since 2025. She received the B.Sc. degree in Physics and Advanced Technology in 2018, and the M.Sc. degree in Advanced Computing and Electronics in 2024, both from UAEH. Her research interests include the Internet of Things (IoT), embedded systems, and applied physics.



Alejandro Monroy-Avelino received the B.Sc. degree in Telecommunications Engineering in 2019. He is currently pursuing the M.Sc. degree in Advanced Computing and Electronics at the Autonomous University of the State of Hidalgo (UAEH), Mexico. He completed international academic stays at Chitkara University, India, and at the University of Santiago de Chile (USACH), Chile, where he pursued engineering-related coursework and research activities. His research interests include embedded systems, electronic design, scientific instrumentation, and distributed sensor networks.



Pedro Miranda-Romagnoli (S'96, AM'97, M'04, SM'25) received the M.Sc. and Ph.D. degrees in Optoelectronics from Autonomous University of Puebla in 1997 and 2002, respectively. Since 2003, he has been a Professor-Researcher in the Department of Mathematics and Physics at the Autonomous University of the State of Hidalgo, Pachuca, Mexico. He is also a National Researcher Level II, within the National System of Researchers of SECIHTI. His research interest lies in optimization techniques for the design of analog electronic circuits and their applications. He has been involved in astroparticle and gamma-ray observatories.



Roberto Noriega-Papaqui received the M.Sc. and Ph.D. degrees in Science (Physics) from the Autonomous University of Puebla, Puebla, Mexico, in 2003 and 2006, respectively. Since 2009, he has been a Professor-Researcher in the Academic Area of Mathematics and Physics at the Autonomous University of Hidalgo, Hidalgo, Mexico. He is currently a National Researcher Level II within the National System of Researchers (SECIHTI). His academic career has focused on theoretical and applied physics. His research interests include advanced computational methods, optimization algorithms, and their applications to physical systems. He has also been actively involved in undergraduate teaching and in the development of scientific and technological innovation projects.