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Article

Implementation of IoT Sensors in Fog Collector Systems and Flowmeters for the Control of Water Collection and Distribution

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Abstract: This study describes the implementation of IoT sensors in drinking water systems and fog collector systems in low-income communities in Ecuador. The influence and handling of these sensors are analyzed, as well as the materials and methods used in their implementation. The importance of validating the accuracy and reliability of IoT sensors compared to professional devices, especially in mountain areas, is highlighted. In addition, it is mentioned that the cost-benefit of using IoT sensors in fog catchers and drinking water networks depends on several factors, such as the scale of the project, specific objectives, and available resources. Finally, it is highlighted that the use of IoT sensors in smart construction and water collection systems has proven to be beneficial in preventing effects on the operation.

Keywords: internet of things (IoT); fog collector systems; drinking water network; cost-to-profit; non-revenue water (NRW)

1. Introduction

The advancement of technology and network connections in IoT sensors, such as data storage, allows us to know in real-time how any ecosystem is functioning, whether it is irrigation, construction, or supply [1–3].

IoT devices installed in construction systems for monitoring allow them to prevent operational risks and control the operational flow to make long-term predictions, as well as behavior analysis [4], in this case, IoT sensors with connection to the grid installed in fog trap towers for water harvesting in areas of difficult access to the resource and in smart flowmeters as part of the drinking water networks within a university [5–13]. Solutions that are more cost-effective than building complex sites or on-site destructive testing [14,15]. Monitoring water consumption in an institution that maintains groundwater wells to supply water helps to quantify the water extracted vs. the water that the well could provide during its useful life, avoiding its permanent drying.

The growth in the use of IoT flowmeters is transforming wastewater management by enabling precise control of volume and flow over the Internet [16]. This provides direct data on actual conditions, facilitating more efficient tracking and more accurate trend analysis. Integration with IoT also enables advanced automation solutions, improving operational accountability and management efficiency [17].

In Ecuador, there are populations in high-altitude areas, where the water resource is difficult to access, which is why it is the impetus of researchers to develop new technologies that help with the

problem and its control in operations through a data history, as is the case of installing IoT sensors to monitor the volume of water captured in fog catchers.

Drinking water and sewage regulations in Ecuador for rural and urban areas stipulate that a drinking water installation is designed for 20-25 years in continuous operation, so in large complexes such as a university it is important to know the status of the system when it completes its design period, new technologies such as the implementation of IoT flowmeters at strategic points to measure the flow of consumption and the taking control of discharges to support hypotheses about how a system is currently doing and to estimate the NRW, which are a very important factor for the formulation of solutions.

The objective of this work was to describe the performance of IoT sensors installed in fog trap towers to generate water in low-income communities in Ecuador, as well as IoT flowmeters installed in the drinking water network of a university center, through real-time monitoring and data collection. Through the results obtained in studies and practical projects where prediction models were generated to capture water from fog and the amount of water that can be generated in various regions of Ecuador was monitored, the profitability of fog catcher systems was compared with traditional drinking water systems. Finally, with the design and installation of IoT flowmeters, consumption patterns were identified, and anomalies were identified in the drinking water network.

2. Applied Study Methodology

To obtain information, a systematic search was used based on data obtained from research from Scopus, Science Direct, and Web of Science, which allowed us to identify relevant studies on the implementation of IoT sensors in drinking water systems and fog collector systems in low-income communities [4]. Subsequently, a meta-analysis was conducted to synthesize the findings and obtain updated references on the performance, feasibility, and efficacy of IoT sensors in water collection and distribution in various contexts.

Meta-analysis, considered a statistical technique used in scientific research, allows the results of multiple independent studies on a specific topic to be combined and analyzed. About the review of individual studies, this methodology allows researchers to integrate data from various related research, thus, obtaining a more accurate estimate of the effect or relationship between variables [18].

Despite its usefulness, the success of a meta-analysis is strongly influenced by the number of studies available and their quality. There is no set minimum number for conducting a meta-analysis, as it depends largely on the question asked. However, those conducted with a larger number of studies are considered to have greater reliability and tend to produce more consistent results, regardless of observed variability [19].

The delimitation of the area of influence, as well as the population to which the application of the different intelligent systems is focused, is detailed below.

3. Influence and Management of the Use of Iot Sensors in Drinking Water Systems

The studies were carried out in the hydro-sanitary system at Universidad de las Fuerzas Armadas ESPE, main campus, in the valley of Los Chillos, province of Pichincha, northwest of Sangolquí, in the highlands region of Ecuador (Figure 1). The specific location is at Av. General Rumiñahui S/N and Ambato, Santa Clara sector [12].

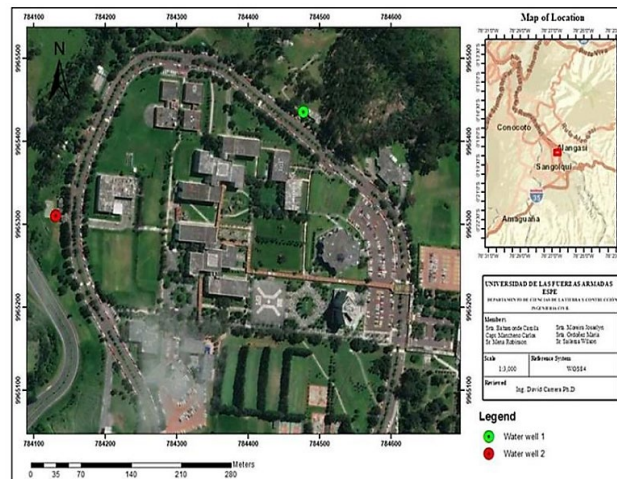


Figure 1. Georeferenced map at Universidad de las Fuerzas Armadas ESPE.

The projects carried out in the institution focus on the analysis of consumption-discharge of the drinking water supply vs. the wastewater network to obtain the percentage of non-revenue water (NRW). The drinking water network that starts from the storage cistern, which supplies most at the university campus, has 4 flow meters installed in Block B, the Administrative Building, and Block C, and a new one installed in 2024 that monitors the University Library. The wastewater network has 3 discharge points which allow for control of the levels of water that go out to the public sewer, located within the university grounds [13].

Implementing IoT Flowmeters in the network of the University's main buildings also made it possible to identify the levels and periods of highest consumption of drinking water generated by the saturation population of 9,785 among students, professors, and administrative staff [13], during the 7 days of the week. With this data, consumption graphs and dynamic models (time series) are created to determine if there is more and more consumption and prevent possible problems in the supply of water resources.

Those projects related to consumption vs. residual discharges also make it possible to identify anomalies or fractures in the drinking water network, due to the age of the hydro-sanitary system [11]. This is presumed with the NRW values of each of the studies carried out in the institution, data and conclusions can be supported with geo-radar or geophone studies.

4. Influence of the Use of IoT Sensors on Towers of Fog Collectors

The availability and distribution of freshwater resources in the world show a great scarcity affecting many regions due to various environmental and social factors, such as changes in geography, climate change, migration of populations, and changes in water supply and use. To this end, a priority approach has been made in the search for new and modern water supply systems through the construction of infrastructures such as pipelines, dams, aqueducts, and treatment plants. In addition, innovative technologies and applications are being explored to supply water to arid or dry regions that have been historically neglected or excluded from central distribution systems [9].

Drought management and adaptation is a central issue in Ecuador's provinces that experience little rainfall at certain times of the year. Lack of precipitation can hurt the availability of water, both for human consumption and agriculture, and can lead to significant challenges in terms of water security in these regions. In this sense, one of the new applications to increase the supply of fresh water has been based on the capture of water by the presence of fog in high mountainous regions [6–8]. It is a structure created to collect moisture from the air, especially in dry or semi-dry areas where the water supply is limited. These structures are very useful in environments where there is little rainfall and obtaining water is a challenge. The main purpose of a fog catcher is to collect the small particles of water present in the fog, condensing them into larger droplets that are then collected and

directed toward storage containers. This ingenious approach harnesses moisture in the air for drinking water or for irrigation in areas where other water sources are limited.

The proposed misting systems may not fully meet the needs described above: communities do not need to obtain 100% water from misting for irrigation, but a certain amount that allows them to irrigate crops on days when water is scarce and there is not enough for their agricultural production to develop regularly [14].

This is a community located in the province of Chimborazo, within the canton of Guamote, in the parish of Palmira, located at a minimum altitude of 3200 meters above sea level. These indigenous communities inhabit a region known as the “Palmyra Desert”, which suffers from water scarcity the other area of study is the province of Pichincha, canton Quito, with the main area identified as the Ilaló volcano, located 8 km from the city. It is an important geographical barrier that is home to a significant amount of biodiversity and has its characteristics with a local microclimate [5]. This benefits the optimization of water harvesting and the monitoring of the performance of fog collectors. The information collected by IoT sensors could be used to adjust the location and orientation of fog towers, as well as to perform preventative and predictive maintenance, which would help maximize atmospheric water harvesting (Figure 2).

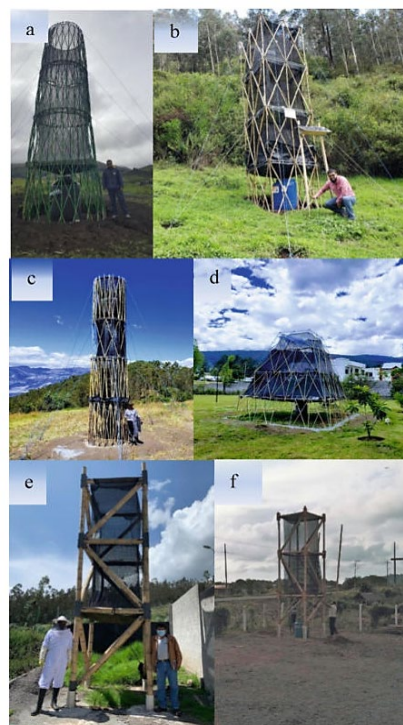


Figure 2. Structural model of fog catchers for communities a) Galte Laime, b) Farm Urku Huayku, c) Ilaló volcano, d) Conocoto Quinta Girasoles, e) Conocoto Parque Metropolitano del Sur, collapsible tower, f) Bunche, collapsible tower.

5. Materials and Methods

5.1. Implementation of IoT Sensors in Flowmeters

In 2021, internet-enabled IoT sensors were deployed to measure the volume of water flowing through a drinking water pipe by reading pulses. This device uses a water flow control meter that features an LCD or a quantitative liquid controller, supplemented by the programming needed to send the collected data to the cloud. This data is reflected in smart devices connected to the internet [12].

Previously, only one IoT device was available in the administrative building. However, the implementation of another similar device was carried out in block B, with the collaboration of students from the subject of Installations in Smart Buildings, who were supervised by Engineer David Carrera, PhD. The devices are synchronized with the online platform <https://thingspeak/> and

<http://thinger.io/>, a verification of the condition of the pipes was carried out in blocks A, B, C, and D (Figure 3). In addition, the availability of the Wi-Fi network was evaluated to prevent potential data loss due to poor signal. A pipe diameter check was also carried out to ensure compliance with technical specifications [13].



Figure 3. IoT flowmeter in Block B and control center.

In the year 2023, a new IoT Flowmeter was implemented in the supply network of block C, led by students led by Engineer David Carrera, PhD, and himself. Completing 3 IoT Flowmeters will allow for obtaining more accurate values of sectorized water consumption throughout the University (Figure 4).

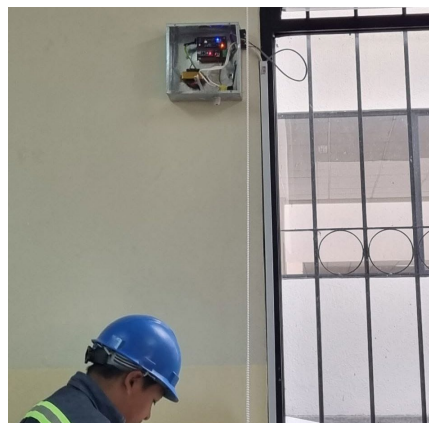


Figure 4. Type control center for each flowmeter installed.

5.2. Implementation of IoT Sensors in Fog Collector Systems

The implementation of IoT sensors in fog towers allows remote and real-time monitoring of different parameters such as humidity, temperature, wind speed, and direction, among others, which helps to optimize water collection efficiency and accurately track the performance of fog collectors. The location of each fog catcher was selected considering a maximum radius of 150 m around the community house so that the point of supply of the collected water remained easily accessible [9].

The construction of the fog catchers with alternative materials, including the main material, reeds. Other materials that were used in the construction were galvanized steel tubes of 3/4" cross-section and thickness of 1.5 mm, polyester mesh 50% and 65% shade, galvanized wire #18, cord, rope, plastic ties, plastic collection tank of 0.2 m³ and 0.5 m³ capacity.

The thicker section reeds were placed in the lower modules (modules that will serve as bases and support the tower's greater load). Reeds with smaller cross-sections should be used for modules going at the top of the tower to reduce the weight of the structure at the top [8].

The implementation of the IoT platform is based on LoRa for communication. This means that it is composed of terminal nodes or sensors that capture the information of environmental variables

and the amount of water captured. These nodes are centralized in a “Lora Gateway”, a gateway that receives the data from the nodes through an RF signal and through a Wi-Fi signal to forward the data obtained as a web service to a database within a server hosted in the cloud (Microsoft Azure); In this way, the data can be monitored remotely, and products can be generated with the information obtained. Figure 5 shows the architecture of the IoT ecosystem [8].

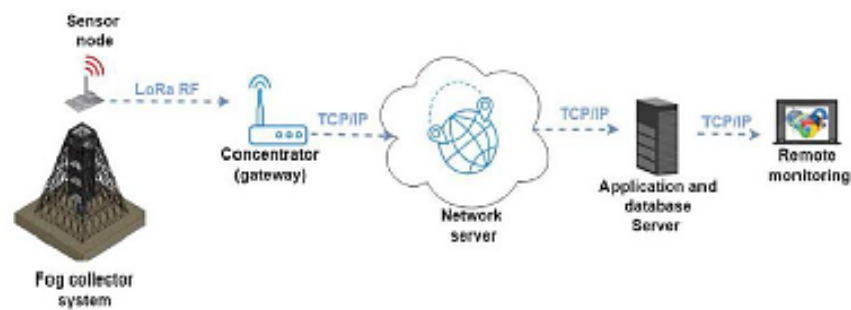


Figure 5. The architecture of the Computer Ecosystem for monitoring environmental variables in the fog trap tower.

Sensors were selected to measure various weather conditions, considering factors such as measurement range, communication protocols, availability, and costs. The monitored variables include wind speed, atmospheric pressure, temperature, relative humidity, visibility level, light, and, crucially, the level of liquid collected, for which a level sensor was employed. Specific details for each sensor can be found in Table 1 [8].

Table 1. Sensor Specifications.

Variable	Model	Communication Protocol	Units	Precision	Measuring Range
Pressure	BME280	12C	hPa	±10	-
Humidity	BME280	12C	%	±15%	0-100%
Temperature	BME280	12C	°C	±0.5	-9°C–65°C
Light	GA1A12S202	12C	Luxes	±5	3-55000
Fluid level	e-tape liquid level-PN-12110215TC-12	Male Crimpflex Pins	(*)	25 mm	0-75 cm
Wind speed	anemometer wind speed sensor W/Analog Voltage Output	-	m/s	1 m/s	0.2-50 m/s
Level of visibility	MiniOFS	5-wire cable	km	+5	20 m–400 m
Date & time	DS3231	12C	-	-	-

5.3. Cost-Benefit Ratio

The benefit of using IoT sensors for water quality and distribution monitoring allows data to be collected remotely and in real-time, making it easier to detect problems in the network where they were installed early [15]. In addition, IoT sensors are low-cost and can make monitoring more accessible in situations where the project does not have a large monetary backing. However, the accuracy and reliability of IoT sensors come at a cost compared to professional equipment to ensure the data collected. Its easy access to long-range Wi-Fi and Bluetooth connectivity highlights the ability to visualize data in online databases and suggest action protocols to users in case of any anomaly, as well as the possibility of dynamic monitoring modules [3,10].

The cost-benefit of using IoT sensors in fog catchers will depend on several factors, such as the scale of the project, specific goals, and available resources. However, we can consider aspects such as accurate monitoring of variables such as wind speed, temperature, humidity, etc., as well as consider

operational efficiency in real-time information from sensors to help optimize the operation of the fog catcher. We will consider operational efficiency by leveraging the real-time information provided by the sensors to optimize the operation of the fog catcher. In addition, it will help save resources by adjusting the operation based on real-time data, making it easier to investigate [1,10].

Mist harvesting technology is a low-investment technique that dispenses with electrical energy and has significantly lower operating costs compared to conventional water supply systems. Unlike the latter, which requires a large upfront investment and generates ongoing expenses for fuel, spare parts, and maintenance, fog water harvesting is relatively cost-effective in areas where it is feasible. As a result, it is possible to provide necessary quantities of water to beneficiary communities efficiently and at a lower cost [10].

6. Results

6.1. Smart Water Collection System

In the Community of Galte, located more than 3500 meters above sea level, a tower of fog collector was implemented in two directions to capture water for cultivation, obtaining an average of 1.91 L/m² per day. Thus, even in other designed towers, the levels of water captured can be monitored as shown in the following image [10] (Table 2).

Table 2. Monitoring of water levels captured in different fog trap towers built.

No.	Model	Peak performance L/m ² /day	Average performance L/m ² /day	Minimum performance L/m ² /day
1	Galte	2.63	1.91	0.65
2	Fog collector in two dimensions	1.33	0.87	0.33
3	Farm Urku Huayku	4.57	0.56	0.07
4	Italo mountain	0.85	0.23	0.1
5	Conocoto Quinta Girasoles	2.52	0.42	5.0
6	Conocoto Parque Metropolitano del Sur	2.20	0.25	0.10
7	Bunche	0.80	0.40	0.00

Data that allows us to verify the amount of water recovered from the fog in each tower, which is an important contribution in mountain communities with difficult access to water catchment.

6.2. Data Obtained by IoT Flowmeters

In real-time, the flowmeter measures the flow of water every 20 seconds, and then this real-time data obtained is saved and monitored through the thinger.io platform, in which it is possible to identify failures in the measurement or disconnection of the equipment (Figure 6).

created_at	entry_id	field1	field2	latitude	longitude	elevation	status		
2023-03-27T17:06:03+00:00	1	0	89				field1 is less than field2		
2023-03-27T17:06:23+00:00	2	1	73				field1 is less than field2		
2023-03-27T17:06:44+00:00	3	2	37				field1 is less than field2		
2023-03-27T17:07:04+00:00	4	3	97				field1 is less than field2		
2023-03-27T17:07:25+00:00	5	4	52				field1 is less than field2		
2023-03-27T17:07:45+00:00	6	5	73				field1 is less than field2		
2023-03-27T17:08:05+00:00	7	6	91				field1 is less than field2		
2023-03-27T17:08:26+00:00	8	7	60				field1 is less than field2		
2023-03-27T17:08:46+00:00	9	8	59				field1 is less than field2		
2023-03-27T17:09:07+00:00	10	9	64				field1 is less than field2		
2023-03-27T17:09:27+00:00	11	10	61				field1 is less than field2		
2023-03-27T17:09:48+00:00	12	11	41				field1 is less than field2		
2023-03-27T17:10:08+00:00	13	12	24				field1 is less than field2		
2023-03-27T17:10:29+00:00	14	13	42				field1 is less than field2		
2023-03-27T17:10:49+00:00	15	14	11				field1 is greater than field2		
2023-03-27T17:11:09+00:00	16	15	73				field1 is less than field2		
2023-03-27T17:11:30+00:00	17	16	5				field1 is greater than field2		
2023-03-27T17:11:50+00:00	18	17	17				field1 equals field2		
2023-03-27T17:12:11+00:00	19	18	38				field1 is less than field2		
2023-03-27T17:12:31+00:00	20	19	68				field1 is less than field2		

Figure 6. Data capture was downloaded from the cloud in March 2023. Source: thinger.io platform.

Figure 7 shows the University’s water consumption analysis interface for the administrative buildings and block B [11].

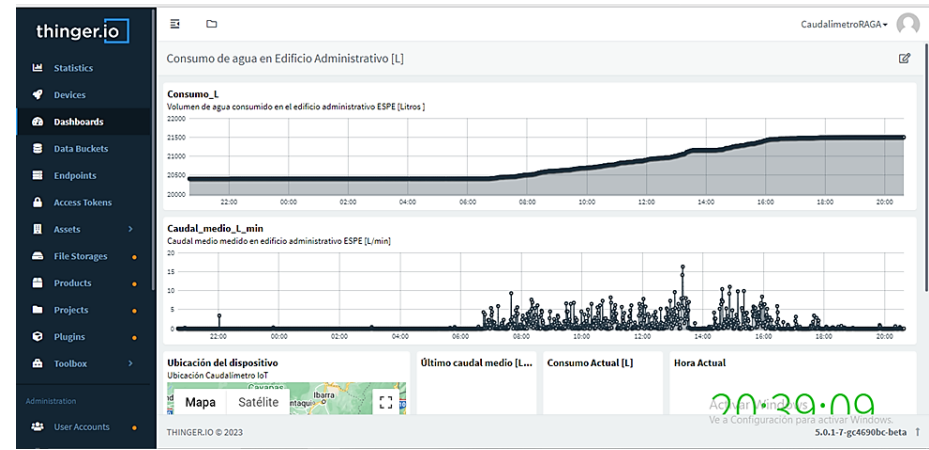


Figure 7. Input interface and control system interface. Source: thinger.io platform.

Once the data has been downloaded and processed in an electronic sheet, we can have the following table, in which the consumption in liters per day is framed [11] (Figure 8).

Day	Flow [L/min]	Volume	Flow [L/día]	Flow [L/min]	Volume	Flow [L/día]
1	16.80	16.80	1221.82	1239.50	1239.50	3520.47
2	1557.90	1574.70	4020.39	31.10	1270.60	1735.81
3	1622.50	3197.20	4006.17	19.00	1289.60	1824.00
4	1836.60	5033.80	3942.61	1354.80	2644.40	3750.31
5	294.40	5328.20	2588.13	1275.30	3919.70	3370.84
6	461.50	5789.70	2251.22	1430.80	5350.50	3765.26
7	2062.50	7852.20	5238.10	1524.60	6875.10	4020.92
8	1326.25	9178.45	3629.42	2012.50	8887.60	4830.00
9	2454.60	11633.05	6155.74	21.50	8909.10	1200.00
10	2009.40	13642.45	5824.35	7.60	8916.70	1403.08
11	1320.80	14963.25	3698.86	1478.80	10395.50	4190.22
12	15.00	14978.25	1200.00	1274.60	11670.10	4351.41
13	6.50	14984.75	1560.00	1725.30	13395.40	5006.92
14	1378.80	16363.55	4001.35	1321.00	14716.40	4343.01
15	1380.00	17743.55	3905.66	24.60	14741.00	2361.60
16	1381.10	19124.65	4077.05	14.70	14755.70	1306.67
17	1398.80	20523.45	3996.57	10.00	14765.70	1333.33
18	1175.70	21699.15	3371.18	1872.70	16638.40	5154.22
19	18.70	21717.85	1068.57	1878.50	18516.90	5026.09
20	22.60	21740.45	2358.26	1506.60	20023.50	4141.86

Figure 8. Capture of processed consumption data per day in the administrative building of the ESPE for an academic period.

With such data, time series, recurrence maps, and comparative graphs of consumption in days, months, or hours can be created. As is the case for 2021, in the study carried out by engineer Rodney Garcés and engineer David Carrera Villacrés PhD. [2], a map of recurrences for February–November 2021 was presented (Figure 9).

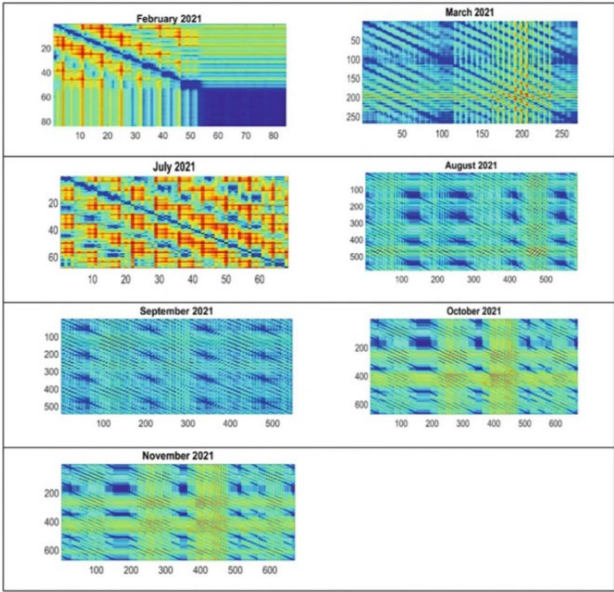


Figure 9. Consumption recurrence map based on IoT flowmeter data in the administrative building.

7. Results Obtained from the Systematic Search

The following studies carried out in different parts of the world concerning the use of IoT sensors are presented (Table 3).

Table 3. Research related to the use of IoT sensors for water management in conduction and catchment.

	Title	Ref.
IoT Flowmeter	Recording Wastewater Treatment Plant Outlet Water Discharge Using Google Sheets	[17]
	Prototipo funcional IOT para determinar la viabilidad de instalación del modelo atrapanieblas tipo chileno en el municipio de Chiquinquirá Boyacá	[20]
	Sistema IoT para el análisis de calidad de agua	[4]
	Automation of Residential Water Flowmeter	[16]
	Optimizing IoT intrusion detection system: feature selection versus feature extraction in machine learning	[21]
	Water contamination analysis in IoT-enabled aquaculture using deep learning-based AODEGRU	[22]
	Internet of Things sensors and support vector machine integrated intelligent irrigation system for the agriculture industry	[23]
	Critical review of water quality analysis using IoT and machine learning models	[24]
	Internet of Things (IoT) enabled water monitoring system	[25]
	Building a Smart Water City: IoT Smart Water Technologies, Applications, and Future Directions	[26]
Fog Collector Systems	Diseño e implementación de torres atrapanieblas (3d) y ecosistema informático de monitoreo con internet de las cosas y aprendizaje automático	[8]
	Potential Solutions for the Water Shortage Using Towers of Fog Collectors in a High Andean Community in Central Ecuador	[9]
	Fog Collectors Systems with IoT Sensors in the Andes and Coastal Regions of Ecuador South-America and Data Processing	[10]

A proposed standard fog collector for use in high-elevation regions	[6]
Eficiencia de captación de agua con tres tipos de malla atrapanieblas en zonas rurales altoandinas de la sierra norte del Perú	[27]
Smallness and Small-device Heuristics: Scaling Fog Catchers Down and Up in Lima, Peru	[28]
FOG WATER TRAPS AS A LOW-COST ALTERNATIVE SOURCE OF WATER IN COASTAL DESERT AREAS OF THE PACIFIC.	[29]
Atmospheric water collection using Three Types of Fog Catchers for high Andean climatic conditions, case: locality 22 de Mayo-Celandines-Perú	[30]
Fog catchers and water collection in a Colombian paramo ecosystem Colectores de niebla en un páramo Andino	[31]

8. Discussion

The use of IoT sensors to monitor the functional levels of a construction system makes it possible to prevent effects in operation and in the future, taking into account that each construction system has a design period and that when complying with it is important to maintain real-time control, or as is also the case in intelligent water collection systems for mountain areas [9]. Implementing smart IoT sensors implies that it has an internet connection at all times to maintain the upload of data to an electronic cloud constantly, a failure in its connectivity requires an operator who knows the operation of the integral system to attend the place for its reconnection [15].

Table 3 shows the most relevant work carried out worldwide on the implementation of IoT sensors in both flowmeters and fog catchers, however, as this is a new and innovative technique, there is not enough information on the subject, so the number of articles and real monitoring data are not sufficient to carry out the meta-analysis with an acceptable degree of reliability.

Engineer David Carrera, PhD. During the last few years, it has taken the initiative to implement intelligent water collection systems in high-altitude areas of Ecuador, such as fog catchers using IoT sensors for monitoring operations, in addition to supporting the study of the drinking water network at Universidad de las Fuerzas Armadas ESPE main campus in Sangolquí city. Ecuador through the installation of IoT flowmeters with connection to the grid, allows real-time consumption data to be obtained at the main points of the institution, which serve to carry out analysis of the consumption and current state of the network since it has fulfilled its optimal design period.

9. Conclusions

The implementation of IoT sensors in drinking water systems and fog towers in low-income communities in Ecuador has proven to be an effective and promising strategy for managing this vital resource. Real-time monitoring has validated the accuracy and reliability of these devices, highlighting their potential to generate predictive models and improve decision-making in environments where access to water is limited or scarce. In addition, the use of IoT sensors in construction and water collection systems offers a cost-effective alternative to ensure efficient operation and prevent potential impacts, such as the detection of leaks and increases in resource consumption. Ultimately, this research provides new perspectives for improving water management in vulnerable communities, offering innovative and sustainable solutions to address the challenges of access to safe drinking water, underscoring the importance of technology in creating a more equitable and sustainable future for all.

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