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Design and implementation of an automatic irrigation system for plants in Lima-Perú

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ABSTRACT

In many regions of the world, water used in agriculture becomes a scarce and costly resource over time. It is necessary to make efficient use of this vital resource. For this reason, we opted for an innovative project that can be of great use for agriculture, incorporating information and communication technologies such as the internet of things (IoT), databases, and smartphone applications. The research proposes an IoT system to control and monitor crops in a specific area based on the ESP32 microcontroller, using the DHT11 sensor to collect temperature and relative humidity data. The sensors send the information to the central node for the wireless communication part. The central node activates the actuators to control and store the information in a database for corresponding monitoring. The mobile application displays the results from the database and causes them to be turned on and off manually. The system was implemented for home plant cultivation but can be used for other types of cultivation due to its flexibility.

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1. INTRODUCTION

In recent decades, technical irrigation has become a fundamental strategy to improve water use efficiency in agriculture. Growing water scarcity, aggravated by climate change, requires more sustainable and effective solutions for managing water resources in crops. Innovative technologies, have enabled the automation of processes in various industries, including agriculture and home automation [1]–[3]. However, despite advances in agricultural automation, these technologies are limited in regions such as Lima, Peru, due to high implementation costs and farmers' lack of technical knowledge.

Solar energy has increased in the last decade, offering environmental and economic benefits. Farmers rely on diesel-powered irrigation systems in many rural areas with no electrical grid. Solar photovoltaic systems eliminate pollution and are a clean alternative. This manual provides information on these solar pumping systems' design, operation, and maintenance [4]–[6].

The increased use of fossil fuels has increased CO2 emissions. Renewable energies, such as solar energy, are being implemented to mitigate climate change. This study analyzes the effectiveness of photovoltaic systems in tropical climates and the effect of growing plants under solar panels. Two identical systems were installed in Thailand for 12 months. The results show that systems with green roofs can generate more electricity than others, thanks to the cultivation of plants, suggesting a higher future energy yield [7]–[9].

In Peru, irrigation technology is nonexistent and very limited due to several factors. Most users lack interest in technological irrigation installations, which leads to a lack of knowledge of the advantages that can be obtained through automatic irrigation [10], [11]. Recent research has shown the feasibility of automated irrigation systems that use the IoT to improve water management and enhance productivity in the agricultural sector. These systems use sensors to monitor environmental conditions and activate irrigation systems only when necessary, helping to optimize water use. However, existing systems have limitations, such as dependence on stable Internet connections, which is only sometimes feasible in rural areas [12].

Manual irrigation can stress plants in conventional irrigation systems due to changes in soil moisture. To improve water use efficiency, the objective is to implement a remote irrigation monitoring and control system through a Wi-Fi module. The sensors collect information about weather, soil moisture, and water levels and send alerts to the user's phone and computer. An app (Blynk) allows the monitoring plant conditions from any location. This system uses sensor devices, NodeMCU and Arduino, to meet the project's objectives [13].

Smart agriculture, fostered by the IoT, aims to improve agricultural production in quantity and quality. This study presents an economical, reliable, and autonomous device that uses solar panels to supply energy to large farming areas. The long range (LoRa) protocol ensures connectivity in areas without internet access, thus allowing fields to be monitored and irrigated only when necessary. The data captured by the sensors is transmitted through the Blynk cloud to mobile app users, evaluating the system in terms of energy savings and water use efficiency, which will help improve agricultural practices [14].

Agriculture has evolved with technology, and the IoT era presents opportunities to improve agricultural efficiency. This work proposes an automatic irrigation system based on the ESP32, which controls and monitors humidity and temperature conditions using DHT11 sensors. Unlike previous systems, this project is designed to be flexible and low-cost, making it ideal for implementation in small urban crops in Lima. In addition, the Blynk platform facilitates monitoring and controlling the system from a mobile device. The system continuously monitors soil conditions and triggers irrigation only when necessary, which proved effective in growing green onions in preliminary and field trials [15].

The main objective of this study is to create a compelling and economical automatic irrigation system that can be implemented in areas with limited resources, promoting the advancement of intelligent agriculture in Lima. This system will use the ESP 32 microcontroller and a DHT11 humidity and temperature controller. The system will have a sensor, water pump, relay, and liquid crystal display (LCD) to display the results obtained. Likewise, all the results obtained will be transferred to the microcontroller database. The microcontroller will detect the acquired values and automatically send all the information to the different output ports in the implemented circuit. Next, in section 2, we will develop the Method; in section 3, we will see the study results and discuss other works; and in section 4, we will present the conclusions of our research.

2. METHOD

The system block diagram is divided into five sections, as shown in Figure 1; we will start by selecting the project idea and the variables in the research. The following section will address the development of the circuit design. Part number three will refer to the materials used. Then, the programming and user interface will be developed, concluding with the implementation and testing. The automatic irrigation system is developed in this section, starting with the project idea and evaluating the planet's growing water scarcity. In addition, the design for solving problems was proposed, the programming in Arduino was developed, and the components' connections were made.

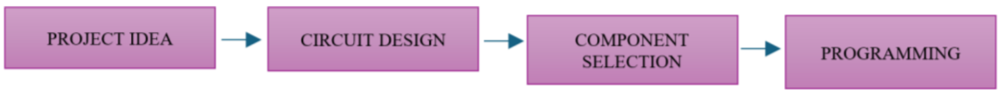


Figure 1. System block diagram

2.1. Project idea

The proposed automatic irrigation system is based on the ESP32 microcontroller, which acts as the central node. DHT11 temperature and humidity sensors were connected to monitor the environmental conditions of the growing area. The ESP32 receives data from these sensors and controls a water pump through a relay based on the measured values. A 5 V source powers the entire system, and communication with the user is done through the Blynk platform, allowing the system to be monitored and controlled remotely using a mobile application.

2.2. Circuit design

Once the project has been conceptualized, we proceed to the design and integration of the hardware system. The proposed system is based on a centralized control architecture that uses an ESP32 microcontroller board as the processing core. Integrating sensors and actuators is essential for irrigation automation, as shown in Figure 2 (system hardware). Firstly, an ambient temperature sensor and an ambient humidity sensor are included, which allow monitoring of environmental conditions that affect soil evapotranspiration. Additionally, the soil moisture sensor directly measures the water in the soil, which is crucial in determining when irrigation needs to be activated. User interaction with the system is carried out through a mobile touch screen (HMI), which allows manual configuration and real-time data monitoring. The data captured by the sensors is processed by the microcontroller board, which makes automatic decisions about activating the actuators. Two relays control the actuators: one for the water pump, which manages irrigation, and another for the solenoid valve, which regulates water flow. Both devices are automatically controlled according to predefined temperature and humidity thresholds, stored and processed on an SD card integrated into the system, allowing historical system data to be recorded. Finally, the system is powered by a power supply that delivers between 5 V and 12 V, providing power to both the board and the external components.

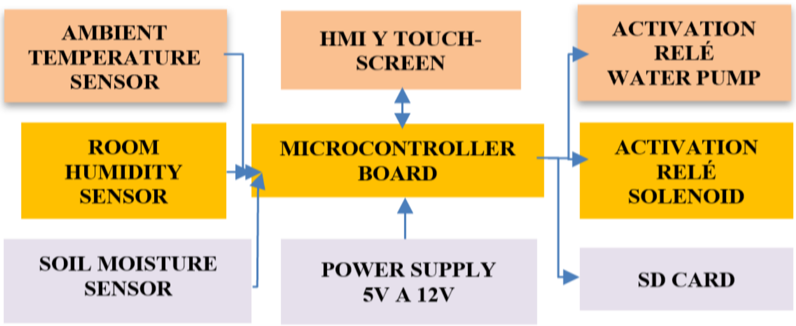


Figure 2. System hardware

2.3. Component selection

2.3.1. ESP 32

Table 1 shows some characteristics of the ESP 32, a powerful microcontroller with integrated Wi-Fi and Bluetooth, featuring two cores up to 240 MHz, plus GPIO and 4 MB of flash memory [16]–[18]. This chip includes an Xtensa LX6 processor, 520 KB SRAM, and connectivity options such as SPI, I2S, I2C, and UART [19]. It also has integrated sensors such as the hall effect [20]. The ESP32 was considered for developing an IoT network that measures climate and temperature values and communicates them via Wi-Fi.

Table 1. ESP32 characteristics

Characteristics	ESP32
Memory RAM	520 KB
Memory flash	Hasta 16 MB
ROM	448 KB
Feeding	2.2 a 3.6 V

2.3.2. DHT11 sensor

Table 2 shows some characteristics of the DHT11. The device has a digital temperature and humidity sensor [21], [22]. It incorporates a capacitive humidity sensor and a thermistor for measuring ambient air, presenting the data through a digital signal on the data pin [23]. It also has no analog output.

2.3.3. Water pump

The ESP32 controls the relay that activates the water pump, allowing it to turn on automatically when the sensors detect that watering is necessary. It will enable the increase in the pressure or flow of water, the extraction of water from a well or reservoir, and the transfer of water from one point to another [24].

Table 2. Characteristics of the DHT11

Characteristics	DHT11
Voltage range	3 to 5 V
Maximum current	2.5 mA máx
Temperature range	0-50 °C/+-2 °C
Humidity scale	20-80%/5%
Sampling rate	1 Hz
Advantage	Low cost

2.3.4. Relay

It is an electrical switch that allows the passage of electric current when closed and interrupts it when open, but it is electrically operated, not manually operated [25]–[27]. The relay will receive the control signal sent by the ESP32 to activate the water pump.

2.3.5. LCD display

It is used for viewing still and moving images. It is formed by many pixels of liquid crystal molecules between two sets of transparent electrodes [28]. It was used to display humidity and temperature values in real time, providing immediate information to the user.

2.3.6. Web ThingSpeak

It is a free-to-use tool for sending sensor data privately and sharing data on public channels. It works with commonly used microcontrollers [29]–[32]. It will show permanent monitoring of the signals the DHT11 sensor receives, personalizing automatic irrigation.

2.4. Programming

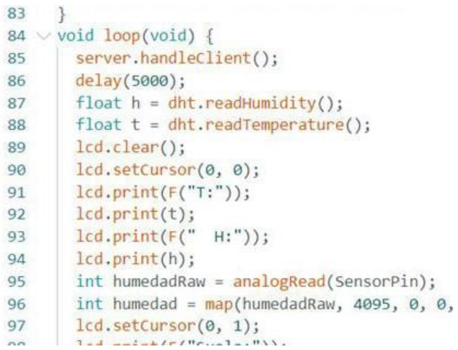
The code implemented in the ESP32 uses several sensors to obtain data on temperature, ambient humidity, and soil humidity, which are presented both on an LCD screen and on a web page accessible through a local Wi-Fi network. In Figure 3, within the handle root() function, variables are declared that store the data read by the sensors (using readDHTTemperature(), readDHTHumidity(), and read soil moisture ()), and a dynamic HTML page is constructed in a buffer, of 2,000 characters (msg), which includes cascading style sheets (CSS) styles and an auto-refresh timer. Figure 4 shows the setup() method, where the serial port is initialized at 115,200 baud, the DHT sensor, the LCD screen (activating the backlight), and the ESP32 is configured as a Wi-Fi access point using Wi-Fi.softAP(), allowing other devices to connect. In Figure 5, the main loop (loop()) runs repeatedly, processing web requests with the server.handleClient(), reading and displaying the temperature and humidity values on the LCD every 5 seconds, and adjusting the display based on the values received. Finally, Figure 6 details the functions of reading the soil moisture sensor data through analogRead(SensorPin) and converting those analog values to a percentage of moisture (0-100%) using the map() function, which facilitates a more intuitive representation of information on the web and LCD interface.

```
void handleRoot() {
  char msg[2000];
  float temperature = readDHTTemperature();
  float humidity = readDHTHumidity();
  int soilMoisture = readSoilMoisture();

  snprintf(msg, 2000,
           "<html>\
  <head>\
    <meta http-equiv='refresh' content='4'/>\
    <meta name='viewport' content='width=device-width, initial-scale=1'>\
    <link rel='stylesheet' href='https://use.fontawesome.com/releases/v5.7.2/css/
    <title>ESP32 Servidor DHT</title>\
    <style>\
    html { font-family: Arial; display: inline-block; margin: 0px auto; text-alig
    h2 { font-size: 3.0rem; }\
    p { font-size: 3.0rem; }\
    .units { font-size: 1.2rem; }\
    .dht-labels{ font-size: 1.5rem; vertical-align:middle; padding-bottom: 15px;]
    </style>\
```

Figure 3. Variable declaration

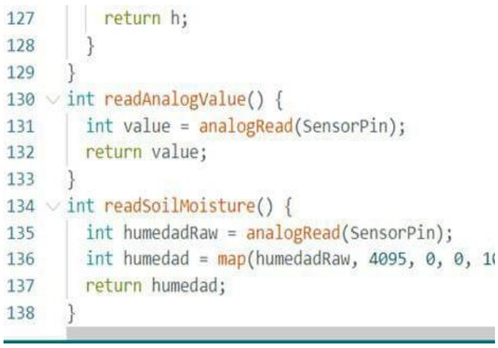
```
void setup(void) {
  Serial.begin(115200);
  dht.begin();
  lcd.init();
  lcd.backlight();

  WiFi.softAP(ssid, password)
```

Figure 4. We start the setup for each component



```
}
void loop(void) {
  server.handleClient();
  delay(5000);
  float h = dht.readHumidity();
  float t = dht.readTemperature();
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print(F("T:"));
  lcd.print(t);
  lcd.print(F("  H:"));
  lcd.print(h);
  int humedadRaw = analogRead(SensorPin);
  int humedad = map(humedadRaw, 4095, 0, 0,
  lcd.setCursor(0, 1);
```

Figure 5. Variable configuration



```
    return h;
  }
}
int readAnalogValue() {
  int value = analogRead(SensorPin);
  return value;
}
int readSoilMoisture() {
  int humedadRaw = analogRead(SensorPin);
  int humedad = map(humedadRaw, 4095, 0, 0, 1
  return humedad;
}
```

Figure 6. Soil sensor data mapping

2.5. System implementation

The system's implementation began with the circuit simulation using the previously mentioned components, as seen in Figure 7. The circuit is composed of an ESP32 microcontroller, which acts as the central core of the system, controlling the reading of sensors and the activation of actuators. A soil moisture sensor and a DHT11 ambient temperature and humidity sensor were integrated connected to the GPIO pins of the ESP32. The values obtained from these sensors are displayed on a 16×2 LCD screen. To control a motor, an L298N module was incorporated, which allows the management of the power supply of a DC motor, using a 9V battery as the primary power source. In this way, the ESP32 can control the irrigation system and the data visualization, all managed from a single integrated platform.

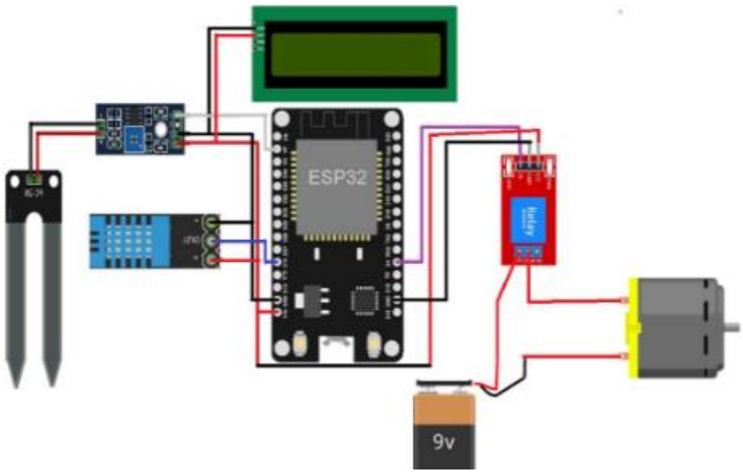


Figure 7. Project simulation

3. RESULTS AND DISCUSSION

As a result, an automatic irrigation system controlled by an ESP32 microcontroller was developed, as seen in Figure 8. This system includes a DHT11 temperature and humidity sensor, which monitors environmental conditions, and a soil humidity sensor, providing critical data to determine the need for watering plants. The ESP32 processes this data and activates a water pump connected to a relay module, which controls the water supply according to the detected humidity levels. The data obtained is displayed on a 16×2 LCD screen, allowing real-time system status monitoring. The water pump is powered by an external source, guaranteeing the system's autonomy.

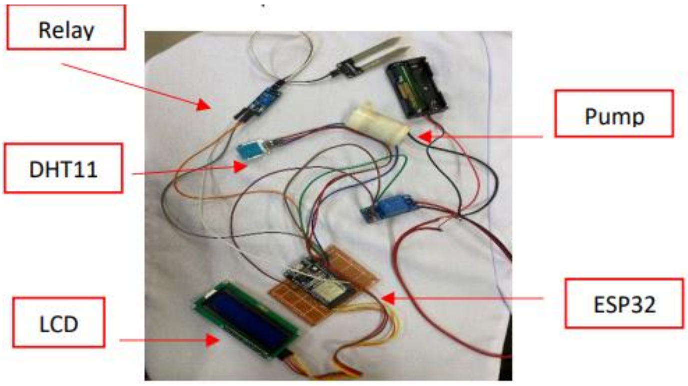


Figure 8. Web ThingSpeak

In the testing stage, the implemented system showed an adequate capacity to monitor and supervise the environmental conditions of the crop in real-time, using specialized sensors to measure critical parameters. The DHT11 sensor, which is responsible for measuring temperature and relative humidity, and the soil moisture sensor generated exact information that was analyzed and sent to the ThingSpeak IoT platform, represented through time series graphs. Figure 9 shows the progression of the ambient temperature, monitored by the DHT11 device. You can notice an initial decrease in temperature, then a gradual increase, and finally, it stabilizes. The behavior suggests that the system is receptive to sudden variations in ambient temperature and can react accurately, which is essential to control the temperature in the growing area. If carried out, the detected variations can lead to automatic ventilation or heating system changes.

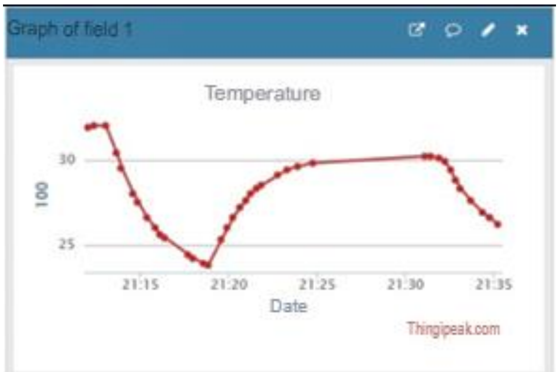


Figure 9. DHT11 sensor temperature data

Figure 10 shows the relative humidity data. The humidity graph shows notable variations in relative humidity levels, also captured by the DHT11 sensor. An initial increase is observed, followed by a gradual decrease, reflecting natural environmental variations, such as evaporation or changes in weather conditions. These data allow exhaustive relative humidity control, which is crucial to preventing fungal diseases and optimizing crop growth. Figure 11 shows soil moisture data. This graph represents soil moisture levels through a specific moisture sensor. Peaks on the graph indicate irrigation or soil saturation events, followed by a stabilization suggesting water uptake by the soil and plants. These data are essential to determine the optimal time for the next irrigation, avoiding both overhydration and drought of the crop, thus improving the efficiency of water use.

Figure 10. Humidity data

Figure 11. Soil moisture data

In Figure 12, an LCD screen connected to the system was implemented, in which the data captured in real-time by the DHT11 sensor is displayed, which measures both the temperature and the relative humidity of the environment, along with the soil humidity. This screen acts as a local interface, giving users a quick and accessible view of the critical environmental parameters for cultivation without additional devices. The system uses the I2C protocol for communication with the display, optimizing the use of microcontroller pins, and allows for constant updating of data, ensuring that the information is current and accurate. On the other hand, Figure 13 shows the implementation of a remote monitoring system through a mobile application, accessible thanks to the system's Wi-Fi connectivity. The data collected by the sensors is transmitted in real-time through a web server hosted on the ESP32, allowing it to be viewed on any mobile device connected to the same network or through a public IP configured for remote access. The mobile interface provides not only the reading of temperature, humidity, and soil moisture values but also the possibility of remotely controlling the activation and deactivation of the water pump, thus facilitating automated and efficient control of the irrigation system, optimizing water resources according to the specific needs of the crop.

Figure 12. Values displayed on the LCD

Figure 13. Housing top view

In Figure 14 you can see the efficiency in the operation of the relay and the water pump, two fundamental elements in the automated control of the irrigation system. The relay works as an electronic switch controlled directly by the signal from the microcontroller. This allows the water pump to be activated or deactivated based on information provided by the soil temperature and humidity sensors. When humidity levels drop below the predefined threshold, the relay closes the circuit, activating the water pump. This ensures that the system automatically responds to environmental variations, providing constant and adequate hydration for the plants. Implementing this system guarantees energy efficiency since the pump is only activated when necessary, optimizing resources. Figure 15 shows the final assembly of the automatic irrigation system, where all the components described above are integrated. Here, you can see how water is distributed evenly to the plants, ensuring that each one receives the appropriate amount according to the readings from the soil moisture sensor. This system is crucial in domestic environments, where the user can not worry about the need to manually water the plants, saving time and improving water use efficiency. This type of technology is of great relevance for today's society, especially in the conservation of water resources and the increase in automation in household tasks, offering accessible and sustainable technological solutions for plant care.

Figure 14. Relay and pump operation

Figure 15. Automatic plant watering

The results obtained in this study show that the implemented automatic irrigation system can effectively monitor the environmental conditions of the crop, triggering irrigation when humidity and temperature values reach the established thresholds. These results are consistent with other studies on IoT-based automated irrigation systems, which have proven effective in optimizing water use in agriculture. Thus, compared to previous studies, such as the work of [12], which describes an irrigation system based on IoT sensors for climate monitoring, our system offers a low-cost and easy-to-implement solution ideal for small urban crops. Furthermore, our approach includes using the ThingSpeak platform, allowing real-time remote control, a feature not present in other studies, and focusing more on conventional irrigation systems without remote monitoring capabilities.

Another relevant comparison is the study of [15], which implemented a drip irrigation system using solar panels. Even though our system does not include a renewable energy source, it is proposed as a future improvement to increase its sustainability, similar to what was suggested by these authors. Furthermore, although both studies employ humidity sensors, our system demonstrates a more efficient real-time integration of the data collected, facilitating more accurate and accessible monitoring from any mobile device.

While our system has demonstrated significant effectiveness, we acknowledge a limitation in its dependence on Wi-Fi connectivity, which could pose challenges in rural areas with limited access. However, promising research, such as that of [14], has explored using the LoRa protocol as a potential solution. This suggests that future iterations of our system could overcome this limitation, offering even more significant potential for widespread application and impact.

Finally, it is essential to highlight that our system not only automates the irrigation process but also provides a constant visualization of the environmental conditions through an LCD screen, which is a significant improvement compared to other systems that do not include this type of visual feedback [28]. This improves the user experience by allowing a more intuitive monitoring of critical variables. In summary, this study's results show an improvement in irrigation efficiency and optimization in water use, aligning with previous studies' findings, but with improvements in accessibility, remote monitoring, and the ability to customize the system according to the specific needs of the crop.

4. CONCLUSION

The proposed automatic irrigation system proved to be an effective and economical solution for irrigation monitoring and control in urban areas with limited access to water. By implementing ESP32 and DHT11 sensors, the irrigation process could be automated based on environmental conditions, thus optimizing water use. One of the main advantages of this system is its ability to be controlled remotely through the Blynk platform, allowing users to monitor and manage irrigation from any location. However, it was determined that the incorporation of renewable energy sources, such as solar panels, could significantly improve the system's sustainability. In future research, there is a promising potential to explore the integration of solar energy to power the system and further reduce energy consumption. Similarly, investigating the implementation of optimization algorithms that allow irrigation thresholds to be automatically adjusted based on local climatic conditions could open up new avenues for improving the system's efficiency.

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AUTHOR CONTRIBUTIONS STATEMENT

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Adrian Humberto Granados-Zárate	✓	✓	✓		✓	✓		✓	✓	✓	✓			
Jhonel Wilfredo Marcatinco-Gonzales	✓	✓		✓	✓	✓	✓		✓	✓		✓	✓	
Martin Fernando Segura-Viteri	✓		✓		✓	✓		✓	✓	✓	✓	✓		
Aldhair Morante-Medina	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Cristian Castro-Vargas	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflict of interest.

INFORMED CONSENT

This study does not involve the participation of human subjects or the use of personally identifiable information, so informed consent is not required.

ETHICAL APPROVAL

This study does not involve using humans or animals, so ethical approval is not required.

DATA AVAILABILITY

The authors confirm that the data supporting the findings of this study are available in the article.

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