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Air Quality Monitoring System with MariaDB Integration and Real-Time Dashboard for Data Visualization

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LoRa Air Quality Monitoring System With Mariadb Integration And Real-Time Dashboard For Data Visualization, Internet of Things (IoT), Particulate Matter (PM1.0, PM2.5, PM4.0, PM10), Volatile Organic Compounds (VOCs), Real-time Monitoring, Cloud Technology, Urban Planning, Environmental Monitoring.

Abstract

This project presents an IoT-based air quality monitoring system designed for indoor environments in smart cities, integrating MariaDB for data storage and a real-time dashboard for visualization. The system addresses the pressing issue of indoor air pollution, which impacts human health by contributing to respiratory issues and reduced productivity. It utilizes the DFRobot SEN0460 sensor to measure particulate matter. Data is collected via the Heltec WiFi LoRa 32 microcontroller and transmitted through LoRaWAN to The Things Network (TTN). Node-RED processes the data, storing it in MariaDB for historical analysis, while Tago IO provides real-time visualization through interactive dashboards with alerts for exceeding air quality thresholds. The methodology includes hardware integration, LoRaWAN transmission software development, and database scripting, validated through repeated operational tests. The system achieved reliable data transmission with minimal packet loss, accurate sensor readings, and efficient solar-powered operation. This solution enhances urban air quality monitoring, supports data-driven public health policies, and promotes sustainability through energy-efficient design.

1. Introduction

Air pollution is a critical environmental and public health issue, contributing to millions of premature deaths globally each year due to exposure to harmful pollutants such as fine particulate matter (PM2.5), carbon dioxide (CO_2), and volatile organic compounds (VOCs). These pollutants originate mainly from industrial activities, vehicle emissions, fossil fuel combustion, and improper waste management, and are known to cause respiratory and cardiovascular diseases. Conventional air quality monitoring systems rely on fixed, high-precision government stations that, while accurate, are costly, bulky, and limited in spatial coverage, particularly in neighbourhood-level, rural, and remote areas.

To address these limitations, this project proposes an Internet of Things (IoT)-based air quality monitoring system that integrates low-cost sensors with long-range, low-power wireless communication. The system utilizes the DFRobot SEN0460 sensor and the Heltec WiFi LoRa 32 microcontroller to measure key environmental parameters including CO_2, VOCs, temperature, and humidity in real time. By employing LoRa technology, the system enables scalable and energy-efficient data transmission, making it suitable for smart city applications, environmental monitoring, and data-driven decision-making to support public health and sustainable development.

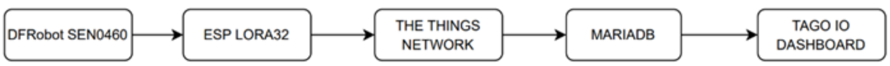
2. Methodology

The development of the LoRa-enabled air quality monitoring system was structured around a modular design that integrates hardware and software components to ensure scalability, sustainability, and real-time functionality. The system was designed for indoor environmental monitoring in smart city contexts, with an emphasis on low power consumption, long-range communication, and accessible data visualization. The primary sensing unit comprises the DFRobot SEN0460 laser dust sensor, which can detect particulate matter concentrations including PM1.0, PM2.5, and PM10. This sensor operates on the principle of laser scattering and provides high-resolution measurements suitable for indoor air quality assessment. Environmental data is collected and processed by the Heltec WiFi LoRa 32 microcontroller, which integrates an ESP32 chip and a LoRa transceiver, enabling both Wi-Fi and LoRaWAN communication capabilities. The microcontroller formats the sensor data into JSON payloads and transmits it wirelessly via the LoRa protocol.

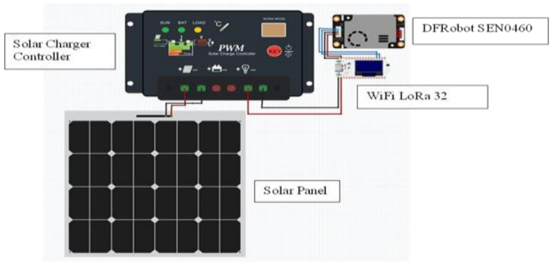
For long-range, low-power data transmission, the system uses a Dragino LoRaWAN gateway that receives uplink packets from the Heltec board and forwards them to The Things Network (TTN), a cloud-based LoRaWAN infrastructure. TTN handles device authentication, data routing, and payload decoding, ensuring a secure, structured data flow to backend applications. A solar-powered energy system was incorporated to ensure autonomous, sustainable operation, particularly for deployments in locations without direct grid access. The power subsystem includes a 12V solar panel, a PWM solar charge controller, and a rechargeable battery pack. The charge controller regulates voltage and current to prevent overcharging and deep discharge, while a DC-DC buck converter provides a stable 5V output to the microcontroller and sensor module. This design ensures continuous operation during periods of low sunlight and enhances the system's suitability for long-term, off-grid monitoring.

The system workflow begins with sensor initialisation and data collection, during which the SEN0460 sensor measures particulate matter via I^2C communication. The Heltec board processes this raw data, formats it, and begins a LoRaWAN transmission sequence. The data is transmitted to the gateway and forwarded to TTN, making it available for further processing. To handle the data flow, Node-RED was used as middleware to parse incoming MQTT messages from TTN. Custom flows were created to decode the sensor payload, extract parameters such as PM1.0, PM2.5, PM4.0, and PM10, and verify data integrity. The processed data is then stored in a locally hosted MariaDB database via XAMPP, providing an organised, query-efficient environment for storing and retrieving historical data.

For end-user accessibility and real-time insights, environmental data is visualized on Tago.IO, a web-based dashboard platform. This dashboard features time-series graphs, numerical indicators, and interactive charts, enabling users to monitor air quality trends and receive automated alerts when pollutant levels surpass set thresholds. Designed with user experience in mind, it offers both desktop and mobile access for stakeholders such as researchers, policymakers, and the public. Figure 1 shows the system architecture, depicting data flow from the DFRobot SEN0460 sensor to the Heltec WiFi LoRa 32 board, then via LoRaWAN to the gateway and TTN. The diagram also highlights the solar power unit and data pipeline through Node-RED, MariaDB, and Tago.IO. The circuit schematic illustrates wiring connections, including I^2C communication, power regulation, and gateway integration. This modular approach ensures the system is functional, reliable, and adaptable for future upgrades, such as adding sensors, machine learning algorithms, or deployment in different environments.



(a)



(b)

Fig. 1 *(a) System Block Diagram; (b) Project Circuit Schematic*

2.1 Project Flowchart

Figure 2 details the data collection and transmission procedure using a DFRobot SEN0460 sensor and LoRaWAN technology. The procedure begins with the initialization of the sensor and system components, including the Heltec WiFi LoRa 32 microcontroller and the LoRaWAN network parameters. Once initialized, the DFRobot SEN0460 sensor gathers environmental data, specifically particulate matter concentrations (PM1.0, PM2.5, and PM10), using laser scattering technology. The raw sensor data is transmitted to the Heltec WiFi LoRa 32 microcontroller via I^2C. Within the microcontroller, the raw data is processed, formatted into a structured JSON payload, and prepared for wireless transmission. The Heltec board then transmits the processed data via LoRaWAN protocol to a Dragino LoRaWAN gateway. The gateway acts as a bridge, receiving the LoRa packets and forwarding them to The Things Network (TTN), a cloud-based LoRaWAN infrastructure responsible for device management, data routing, and payload decoding.

A decision point in the system flow determines whether the data upload to TTN succeeds. If the transmission is successful, the data is stored in the MariaDB database via Node-RED middleware, and a timer is initiated to wait for 1 minute before the cycle repeats. This periodic transmission approach balances data freshness with energy efficiency, aligning with the system's low-power design. If the upload fails, the system enters a retry state or triggers a local alert to ensure data integrity and system reliability. This structured workflow enables continuous, real-time air quality monitoring with minimal manual intervention.

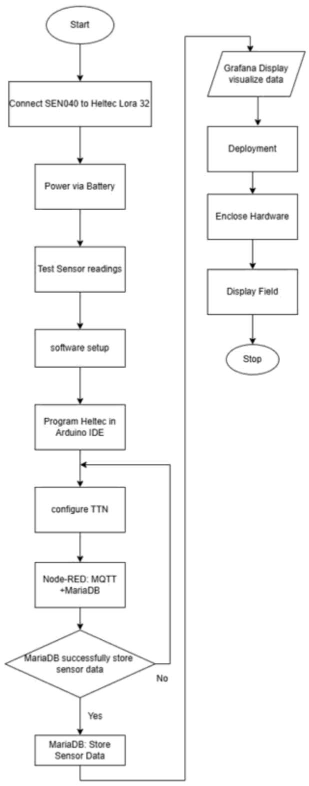


Fig. 2 *System Flowchart*

3. Results

The system's real-time data acquisition capability was validated through consistent, successful uplink transmissions to The Things Network (TTN). Data packets containing sensor readings for particulate matter concentrations (PM1.0, PM2.5, PM10) were reliably received and confirmed via the TTN console interface. The Node-RED flow parsed these incoming packets and inserted the extracted values into a structured MariaDB database, with verification through continuous log entries and the stable operation of the local database server running on XAMPP. These results confirm the system's ability to maintain reliable long-range communication with minimal packet loss and low latency.

Data visualization through Tago.IO dashboard demonstrated the system's effectiveness in delivering clear, actionable, real-time insights. Interactive graphical panels displayed time-series trends in particulate matter levels, while tabular views enabled detailed inspection of recorded data. For example, time-series plots revealed expected diurnal fluctuations in PM2.5 concentrations, and sensor stability was confirmed through consistent readings across varying indoor environmental conditions. The system's ability to log and visualize data at one-minute intervals provided high temporal resolution, supporting accurate trend analysis and anomaly detection.

The end-to-end functionality of the LoRaWAN-based air quality monitoring system was evaluated through a series of operational tests encompassing real-time data collection, wireless transmission, and cloud-based visualization. The system consistently transmitted sensor data to TTN, where the payloads were decoded and forwarded to Node-RED for processing before being stored in MariaDB. The TTN console (Figure 3) displayed a steady stream of uplink packets, confirming the reliable performance of the Heltec WiFi LoRa 32 microcontroller in sending air quality data to the cloud.

Overall, the findings indicate that the developed system provides high-resolution environmental monitoring, low power consumption, and robust data integrity, making it well-suited for scalable deployment in smart city applications. The integration of solar power further enhances its sustainability and suitability for long-term, unattended operation in diverse indoor settings.cloud.

Fig. 3 *Uplink Data Received on The Things Network Console*

Subsequently, the decoded data was passed into Node-RED, where each parameter such as PM1.0, PM2.5, PM10, and other environmental metrics were individually extracted and routed to the MariaDB database. As shown in Figure 4, the Node-RED interface enabled real-time visualization of the incoming data payload and confirmed successful parsing, validation, and storage.

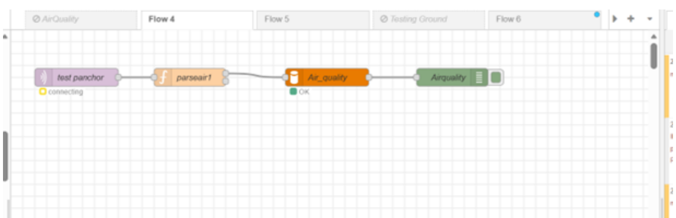


Fig. 4 *Node-RED Dashboard Displaying Parsed Sensor Data*

Once stored in the MariaDB database, the data was visualized using the Tago.IO dashboard platform, enabling both real-time and historical monitoring. Figure 5 presents an example of the dashboard layout, which includes dynamic gauges, time-series graphs, and tabular views for different particulate matter parameters. The system also supports real-time plotting of air quality metrics, as illustrated in Figure 6, where fluctuations in PM1.0, PM2.5, and PM10 concentrations are clearly displayed across selected time intervals, allowing users to track trends and identify pollution events as they occur.

Fig. 5 *Tago. IO dashboard Showing PM and Access Logs*

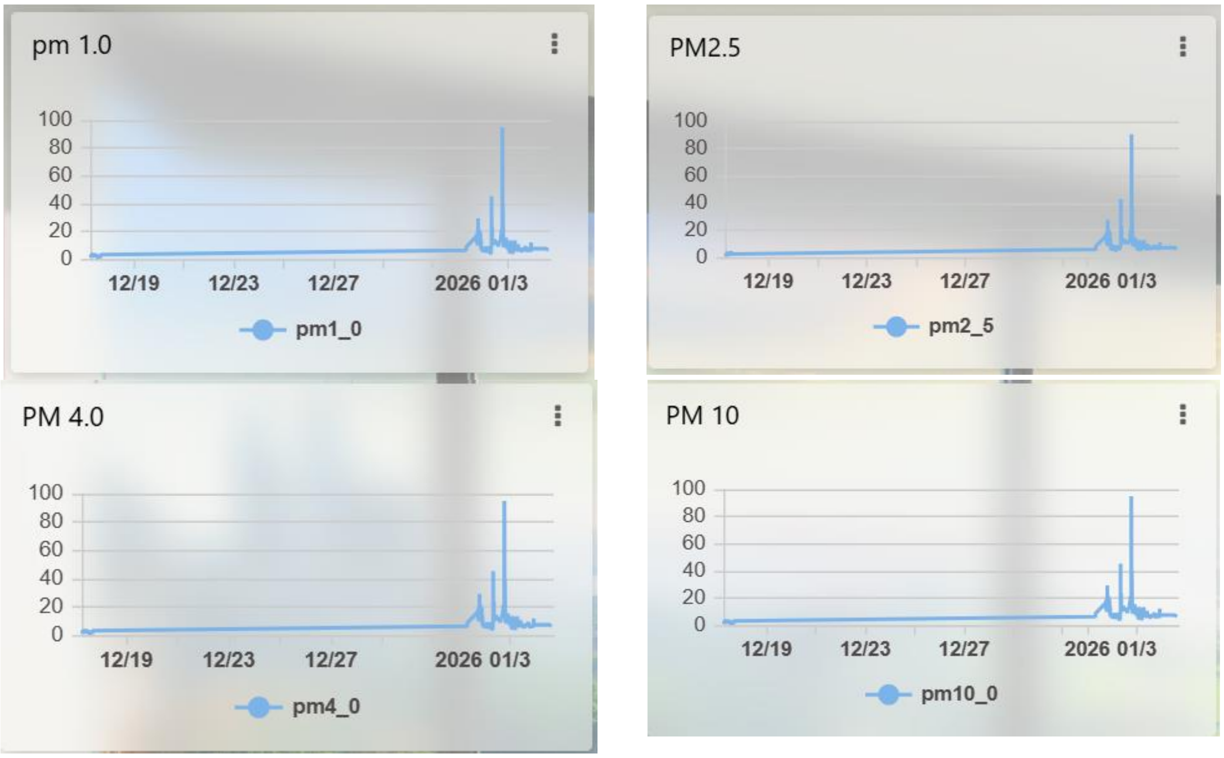
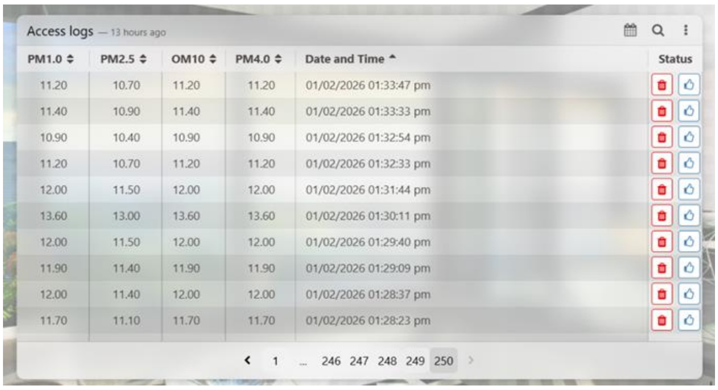


Fig. 6 *Time-Series Graphs of Air Quality Parameters in Tago. IO*

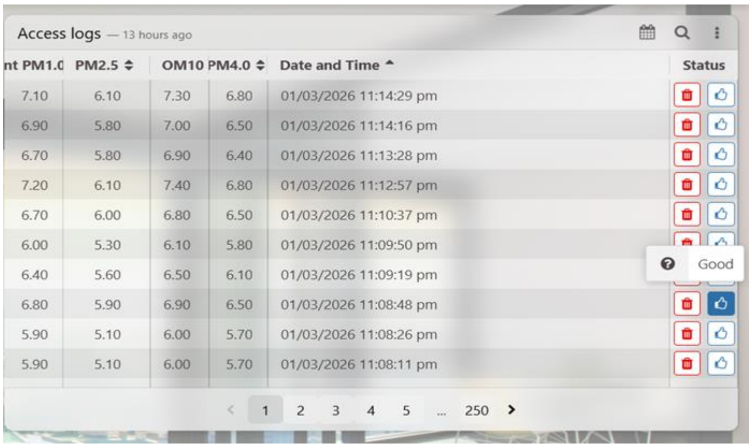
The graphical outputs confirmed that the system could continuously collect accurate environmental data and present it in an accessible format. Furthermore, the access log tables in Figure 7 and 8 provide additional validation by showing timestamped records of PM concentrations over consecutive days, confirming the system's ability to detect variations in particulate matter levels. These results illustrate the feasibility of deploying such systems in urban indoor environments to improve air quality monitoring and support data driven.


Access logs — 13 hours ago

PM1.0	PM2.5	OM10	PM4.0	Date and Time	Status
11.20	10.70	11.20	11.20	01/02/2026 01:33:47 pm	
11.40	10.90	11.40	11.40	01/02/2026 01:33:33 pm	
10.90	10.40	10.90	10.90	01/02/2026 01:32:54 pm	
11.20	10.70	11.20	11.20	01/02/2026 01:32:33 pm	
12.00	11.50	12.00	12.00	01/02/2026 01:31:44 pm	
13.60	13.00	13.60	13.60	01/02/2026 01:30:11 pm	
12.00	11.50	12.00	12.00	01/02/2026 01:29:40 pm	
11.90	11.40	11.90	11.90	01/02/2026 01:29:09 pm	
12.00	11.40	12.00	12.00	01/02/2026 01:28:37 pm	
11.70	11.10	11.70	11.70	01/02/2026 01:28:23 pm	

1 ... 246 247 248 249 250

Fig. 7 *Access Log Data from Tago IO on day 1*


Access logs — 13 hours ago

nt PM1.0	PM2.5	OM10	PM4.0	Date and Time	Status
7.10	6.10	7.30	6.80	01/03/2026 11:14:29 pm	
6.90	5.80	7.00	6.50	01/03/2026 11:14:16 pm	
6.70	5.80	6.90	6.40	01/03/2026 11:13:28 pm	
7.20	6.10	7.40	6.80	01/03/2026 11:12:57 pm	
6.70	6.00	6.80	6.50	01/03/2026 11:10:37 pm	
6.00	5.30	6.10	5.80	01/03/2026 11:09:50 pm	
6.40	5.60	6.50	6.10	01/03/2026 11:09:19 pm	Good
6.80	5.90	6.90	6.50	01/03/2026 11:08:48 pm	
5.90	5.10	6.00	5.70	01/03/2026 11:08:26 pm	
5.90	5.10	6.00	5.70	01/03/2026 11:08:11 pm	

1 2 3 4 5 ... 250

Fig. 8 *Access Log Data from Tago IO on day 2*

4. Conclusion

The Air Quality Monitoring System With Mariadb Integration And Real-Time Dashboard For Data Visualization represents a significant advancement in environmental monitoring for smart cities, offering an innovative, cost-effective, and scalable solution for real-time air quality assessment in indoor environments. This system effectively integrates advanced LoRaWAN communication with the DFRobot SEN0460 particulate matter sensor, overcoming the limitations of traditional monitoring systems by reducing deployment costs, extending coverage through long-range wireless transmission, and improving energy efficiency through its low-power design and solar-power operation. By providing actionable, real-time air quality data through the Tago.IO dashboard, the project enables proactive environmental management, empowering stakeholders to monitor pollution trends and implement targeted mitigation strategies to enhance public health and urban sustainability.

Future efforts will focus on expanding sensor network coverage, incorporating machine learning for predictive air quality modeling, enhancing user engagement through mobile and web-based interfaces, and exploring interoperability with other smart city platforms and IoT infrastructures. These developments will further strengthen the system's relevance and applicability in ongoing smart urban initiatives.

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