Volume 2, Issue 1

Innovation Series Quarterly

https://journal.academicapress.org/aps/index.php/isq

Research Article

Design of a Web-Integrated IoT System for Environmental Monitoring Using ESP32

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Keywords:
Environmental Monitoring
IoT
ESP32
MySQL
Tomcat

Abstract: *This project presents the design and implementation of a web-integrated IoT environmental monitoring system using the ESP32 microcontroller. The system measures temperature, humidity, air quality, atmospheric pressure, altitude, and light intensity using the BME680 and LDR sensors. Sensor data are transmitted via Wi-Fi to an Apache Tomcat server and stored in a MySQL database. Data was visualized through a real-time JSP-based web dashboard. Testing showed stable communication, accurate sensor readings, and reliable data retrieval with no packet loss. Real-time and 10-minute interval displays demonstrated consistent environmental trends, confirming the system's capability for continuous indoor and outdoor monitoring. The results indicate that the proposed architecture is effective, low-cost, and suitable for future extension into multi-node or cloud-based applications.*

1. INTRODUCTION

The rapid development of Internet of Things (IoT) technologies has enabled low-cost, real-time environmental monitoring systems capable of measuring multiple parameters simultaneously. Such systems are increasingly used indoor air-quality assessment, agricultural management, and smart-building applications due to their ability to provide continuous and remotely accessible data streams. Recent studies highlight that IoT-based monitoring solutions offer significant advantages in cost, scalability, and accessibility compared to conventional wired or laboratory-based approaches (Witczak & Szymoniak,2024).

2. LITERATURE REVIEW

Microcontrollers such as the ESP32 have become central to modern IoT deployments because of their built-in Wi-Fi connectivity, low power consumption, and ability to interface directly with multi-functional sensors. Research shows that ESP32-based platforms can reliably collect and transmit environmental data in real time, making them suitable for compact environmental monitoring nodes (Omkar et al., 2024). Likewise, multi-sensing components such as the BME680 enable the measurement of temperature, humidity, atmospheric pressure, and gas concentration from a single device, further reducing hardware complexity and system cost. Similar sensor–microcontroller integrations have been successfully demonstrated in agricultural and indoor monitoring projects (Karag et al., 2025). In addition to hardware advancements, lightweight web-based systems have become an effective method for storing and visualising environmental data. Server-side technologies such as Apache Tomcat, combined with MySQL databases and dynamic web pages, enable efficient transmission, processing, and display of real-time sensor readings. Studies show that these architectures, when paired with Wi-Fi-enabled microcontrollers, achieve stable communication and reliable data acquisition for continuous monitoring purposes (Dewi et al., 2025). A comparison with selected recent studies is presented in Table 1. The comparison focuses on system cost, monitored parameters, and architectural flexibility.

Table 1. Comparison of Proposed System with Related Works

Feature / Study	Dewi et al. (2025)	Omkar et al. (2024)	Proposed System
Controller	ESP8266	Raspberry Pi	ESP32
Communication	Wi-Fi (HTTP)	Wi-Fi (Cloud-based)	Wi-Fi (Local Server)
Monitored Parameters	Temperature, Humidity	Multiple Environmental Sensors	Temperature, Humidity, Gas, Light
Database	Cloud Platform	Cloud Platform	MySQL (Local)
Scalability	Limited	High (Cloud dependent)	High (multi-node ready)
Cost	Medium	High	Low
Real-Time Dashboard	Yes	Yes	Yes

Based on the comparison, the proposed system offers a cost-effective and flexible architecture, leveraging ESP32 and a local MySQL server while maintaining real-time visualization capabilities. Unlike cloud-dependent solutions, this approach reduces operational cost and dependency on external services, making it suitable for educational, small-scale industrial, and research applications. The architecture also provides a strong foundation for future security and scalability enhancements.

The objectives of this project are to develop an IoT-based environmental monitoring system using ESP32 for real-time acquisition of environmental data, to design a web-integrated dashboard using HTML and JSP for visualisation of sensor data, and to implement a reliable communication architecture between ESP32, MySQL database, and the web interface using Apache Tomcat. The system design is as shown in Figure 1, it includes implementation and performance evaluation, but excludes predictive analytics, cloud integration, and long-term multi-node deployment, which are recommended for future work.

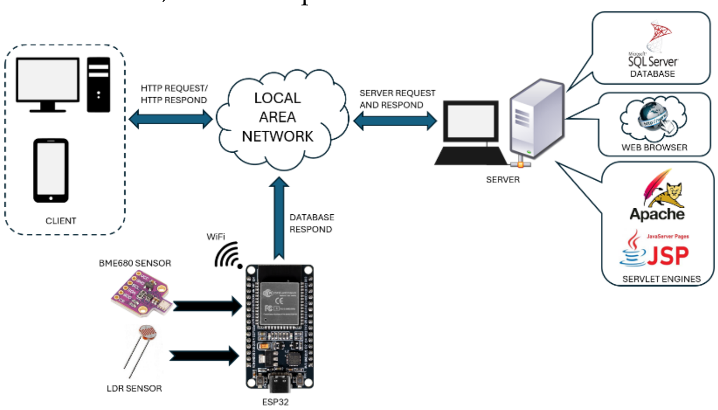

Figure 1. Web-Integrated IoT System for Environmental Monitoring Using ESP32

3. METHODOLOGY

The methodology of this project is structured into four main phases: requirement analysis, hardware implementation, software development, and system validation. Figure 2 is the block diagram describing the monitoring system that has been developed. The system measures five key parameters, which are temperature, humidity, air quality, atmospheric pressure, altitude and light intensity. The data is displayed through a real-time JSP-based web dashboard. Data transmission, storage, and retrieval are handled using an ESP32 firmware–Tomcat–MySQL architecture. The project focuses on a single-node, outdoor environmental monitoring setup using the ESP32 microcontroller with five parameters: temperature, humidity, air quality, atmospheric pressure and altitude, and light intensity. The data are transmitted via HTTP POST to an Apache Tomcat server and stored in a MySQL database for dashboard visualisation. The Root Mean Square Error (RMSE) was employed to quantify the deviation between the ESP32 temperature readings and the public meteorological reference data. RMSE is widely applied in low-cost environmental monitoring research to evaluate the performance of sensor systems against trusted reference measurements (Kang et al., 2021). A lower RMSE indicates closer agreement between the measured and reference values, providing a meaningful indication of system reliability for real-time monitoring applications.

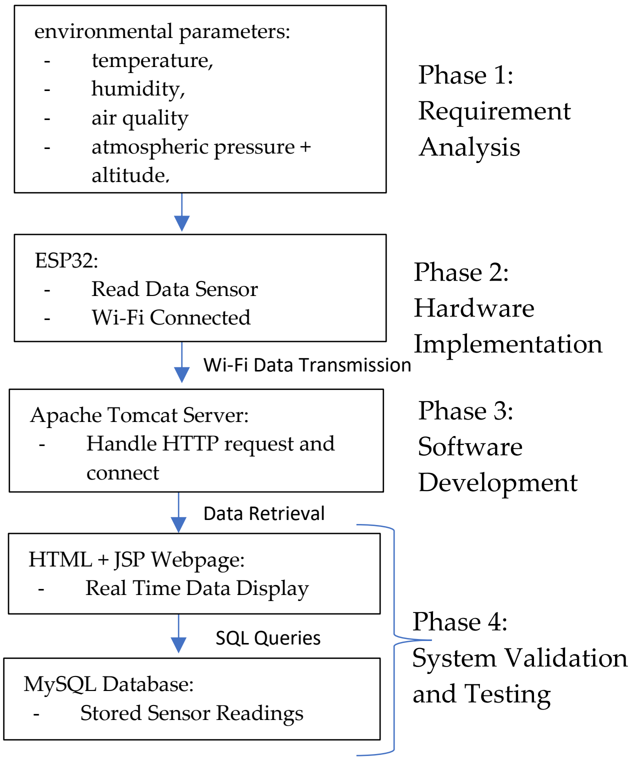

Figure 2. Block Diagram of the System

4. FINDINGS

The development of an IoT-based environmental monitoring system has successfully measured and displayed five environmental parameters (temperature, humidity, air quality, atmospheric pressure, altitude and light intensity) in real time through a web-integrated dashboard. Figure 3 shows the final web interface generated using HTML and JSP, where all sensor readings are sent to the MySQL database by the ESP32. The data presented to the user were retrieved from the MySQL database. The system demonstrated stable communication between the ESP32 and the Apache Tomcat server. Sensor readings were transmitted via HTTP POST at 1-second intervals without packet loss during testing. The MySQL database consistently stored time-stamped sensor data, enabling historical tracking and retrieval. This behaviour aligns with similar IoT monitoring systems reported by Dewi et al. (2025), where ESP32-based environmental data acquisition showed reliable network communication and minimal latency.

4.1 Real-Time Dashboard Visualization

The real-time dashboard demonstrated smooth rendering of new sensor values without manual page reloads. The auto-refresh mechanism performed consistently, and the retrieval of data from MySQL showed no observable delay. These results validate the effectiveness of the web-integrated IoT architecture adopted in this project, consistent with findings from recent IoT environmental monitoring frameworks (Witczak & Szymoniak, 2024). The system achieved its objective of providing real-time, network-based environmental monitoring using ESP32 as the primary controller.

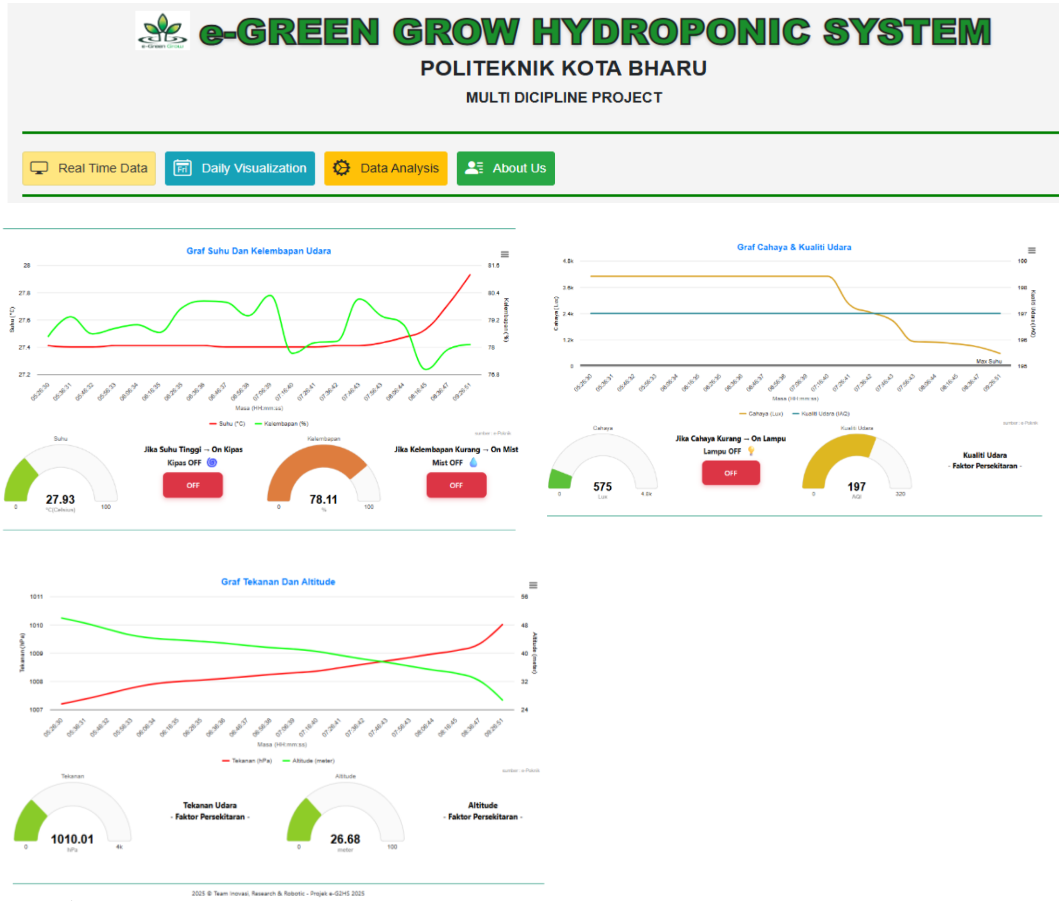

Figure 3. Webpage Integrated Dashboard Monitoring system for Real-Time Visualization

4.1.2 10-Minute Interval Database Dashboard Visualisation

The 10-minute interval data demonstrated that the system is capable of long-term, continuous monitoring with minimal drift, stable data transmission, and accurate representation of daily environmental behaviour. The results from Figure 4 reinforce the reliability of the integrated ESP32 with BME680 architecture and validate the system's effectiveness for daily trend monitoring and historical analysis for five key parameters: temperature, humidity, air quality, atmospheric pressure and altitude, and light intensity.

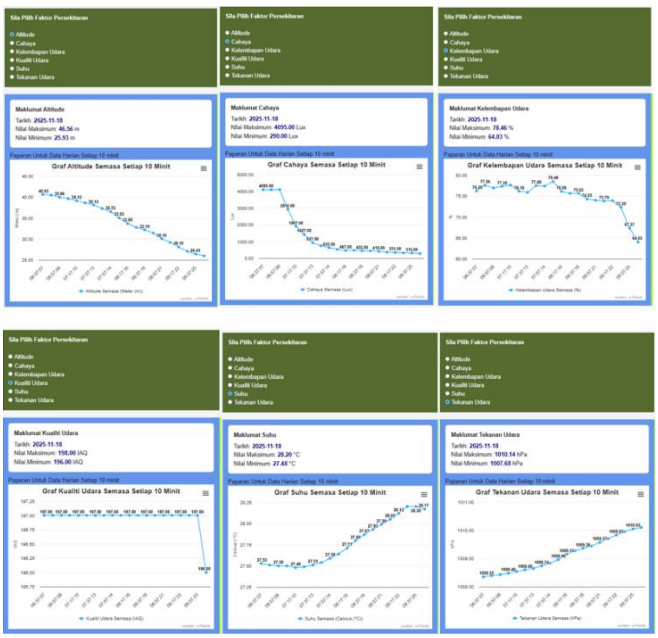

Figure 4. Webpage Integrated Dashboard Monitoring System for 10-minute Intervals Visualization

To quantitatively evaluate temperature measurement consistency, data collected by the ESP32-based system were compared with publicly available meteorological reference data obtained from AccuWeather. Both datasets correspond to the Kok Lanas, Ketereh region. Since the proposed system records data at 10-minute intervals while AccuWeather provides hourly readings, the ESP32 data were aggregated into hourly averages to ensure temporal alignment. The Root Mean Square Error (RMSE) was employed to quantify the deviation between the two datasets. The analysis yielded an RMSE value of 2.64 °C, indicating an acceptable level of deviation and consistent temperature trends over the monitoring period. This result demonstrates that the proposed system provides reliable temperature monitoring suitable for indoor and outdoor environmental applications.

5. DISCUSSION

The experimental results indicate that the ESP32 integrated with BME680 and LDR sensors provides a reliable platform for continuous outdoor environmental monitoring. The proposed system architecture, consisting of ESP32 firmware, Apache Tomcat middleware, and a JSP–MySQL web interface, operated cohesively and supported stable real-time and interval-based data acquisition. Sensor readings showed consistent and expected environmental variations, in agreement with previous ESP32-based monitoring studies (Dewi et al., 2025; Omkar et al., 2024).

To further evaluate measurement reliability, temperature data from the ESP32 system were compared with publicly available meteorological reference data obtained from AccuWeather. Due to differences in sampling resolution, ESP32 data collected at 10-minute intervals were aggregated into hourly averages prior to comparison. The Root Mean Square Error (RMSE) was calculated as 2.64 °C, indicating acceptable deviation and consistent temperature trends. As the reference data represent outdoor, area-level conditions while the ESP32 sensor measures localized outdoor temperature, the comparison focuses on trend consistency rather than absolute calibration accuracy.

Although the current prototype employs HTTP for data transmission due to implementation simplicity, future enhancements may incorporate HTTPS or MQTT with Transport Layer Security (TLS) to improve communication security. In addition, the system architecture is scalable and can be extended to multi-node deployments by incorporating unique device identifiers within the MySQL database, enabling centralized data management and improved performance as data volume increases.

6. CONCLUSION

This study presented a web-integrated IoT environmental monitoring system using the ESP32 microcontroller with BME680 and LDR sensors to measure key environmental parameters, including temperature, humidity, air quality, pressure, altitude, and light intensity. The system demonstrated reliable operation, stable Wi-Fi communication, and effective real-time visualization through a JSP–MySQL dashboard. Quantitative evaluation using RMSE analysis confirmed consistent temperature trends when compared with public meteorological reference data.

The results support existing research on the suitability of ESP32-based platforms for low-cost, real-time environmental monitoring (Dewi et al., 2025; Omkar et al., 2024; Witczak & Szymoniak, 2024). While the current implementation focuses on a single outdoor node, the proposed architecture provides a strong foundation for future enhancements, including secure communication protocols, multi-node expansion, and cloud-based analytics to support broader monitoring applications (Karag et al., 2025).

Acknowledgments: We would also like to express our gratitude to institutions, all family members and friends, for the love and support they have provided.

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