Smart Weather Monitoring for Coffee Plantations: IoT-Based Automated Data Logging and Agronomic Decision Support

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Abstract. Weather information is a crucial factor in supporting agricultural activities, particularly in tropical regions like Indonesia, which frequently face climate variability and extreme weather phenomena. This research aims to design and implement an Internet of Things (IoT)-based Automated Weather Station (AWS) for a coffee plantation in Perteguhan Village, Simpang Empat District. The system uses an ESP32 microcontroller and a SIM7600A communication module to collect real-time weather data, including air temperature, relative humidity, and wind speed and direction. Data is sent via the MQTT protocol to a cloud database (Google Sheets) and displayed via a Kodular-based mobile application, which is also integrated with weather forecast data from the Meteorology, Climatology, and Geophysics Agency (BMKG). In addition to monitoring, the system is equipped with a decision tree model that processes a combination of sensor data and literature to generate agronomic recommendations. A one-month field trial demonstrated stable system performance with minimal data loss, and measurement results were consistent with secondary data from the BMKG API. The results of this study indicate that the developed IoT-based AWS is practical, affordable, and scalable, thus having the potential to support agronomic decision-making, increase farmers' resilience to climate variability, and strengthen sustainable agricultural practices in rural communities.

Keywords: IoT, Automated Weather Station, Agriculture, Data Logging, Decision Support

1 Introduction

Climate variability and extreme weather events pose major challenges to agricultural productivity in tropical regions such as Indonesia. Farmers traditionally rely on local knowledge

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and past experiences for decisions related to planting, irrigation, and harvesting. However, increasing weather unpredictability has rendered such practices insufficient for managing risks. Reliable and continuous weather information is therefore a critical resource to strengthen farmers' adaptive capacity and support climate-resilient agricultural practices. As highlighted by [1], access to accurate and timely weather information, facilitated through information and communication technologies (ICTs), significantly enhances the adoption of farm-level adaptation strategies. Yet, smallholder farmers in rural areas often lack access to localized and affordable weather data, leaving them vulnerable to climate shocks.

The urgency of localized monitoring is evident in Indonesia, where climate-related hazards such as floods and droughts have increasingly disrupted agricultural productivity. A recent study in West Java showed that extreme climate events significantly reduced paddy field yields, underscoring the need for site-specific monitoring and adaptive strategies [2]. While large-scale hazard modelling contributes to national food security planning, complementary solutions are needed to deliver real-time, plantation-level weather information directly to farmers.

Recent advances in the Internet of Things (IoT) and web services have transformed traditional farming into smart agriculture, enabling real-time monitoring, cloud-based analytics, and remote decision support. These technologies improve resource efficiency, reduce waste, and enhance sustainability, though challenges such as implementation cost, data privacy, and limited technical expertise remain [3]. Within this context, IoT-based Automated Weather Stations (AWS) provide a practical solution to generate localized microclimate data for plantation management.

This study aims to design and deploy an IoT-based Automated Weather Station (AWS) tailored for coffee plantations in Indonesia. The system integrates real-time sensor data with external weather information from the BMKG API, and further enhances its utility through decision-tree-based agronomic recommendations. A mobile application is developed to provide farmers with an accessible platform for weather monitoring and decision support. By combining IoT, national meteorological data, and machine learning–based agronomic insights, this research contributes a scalable and practical approach for supporting climate-resilient coffee farming in rural communities.

The application of Internet of Things (IoT) technologies in precision agriculture has been widely explored to address challenges related to climate variability, crop productivity, and irrigation efficiency. One notable example is the IoT-Agro system in Colombia, which integrates perception, edge computing, and data analytics to support smart farming in coffee plantations, demonstrating how localized weather data can enhance decision-making for crop management [4].

In the Indonesian context, [5] developed a solar-powered Automatic Weather Station (AWS) based on ESP32 and GPRS modules, capable of measuring multiple meteorological parameters and transmitting them to a cloud server. Their system achieved a 98% data transmission success rate and was designed to support irrigation modernization, underscoring the potential of AWS for agricultural resilience in rural areas.

Similar AWS implementations have been reported worldwide, utilizing various IoT communication technologies such as LoRa, ZigBee, and Wi-Fi to achieve low-power, long-range connectivity for agricultural monitoring [6][7][8][9]. or instance, Project PANTHEON in

Europe integrated IoT-based agrometeorological monitoring with a SCADA system combining aerial and ground robots for precision management of hazelnut orchards [10], while mobile robotic platforms like ByeLab have been deployed for proximal canopy sensing in orchards [11].

Despite these advances, a significant research gap remains in the real-world deployment of AWS tailored for smallholder coffee plantations, particularly those that integrate localized weather data with decision-support algorithms for agronomic recommendations. This study aims to address this gap by designing and deploying an IoT-based AWS in a rural Indonesian coffee plantation, enhanced with BMKG weather API integration and decision-tree-based agronomic support delivered via a mobile application.

3 Methods

3.1 Hardware

The IoT-based Automated Weather Station (AWS) is built around the ESP32 microcontroller, which functions as the core processing unit. The hardware components include:

1. Meteorological Sensors: temperature, humidity, and wind speed.
2. Power Supply: a 20 Wp solar panel, Solar Charge Controller (SCC), and a 12V/6Ah battery for energy storage.
3. Peripheral Modules: SIM7600C GSM module for data transmission, and voltage sensors for battery monitoring.

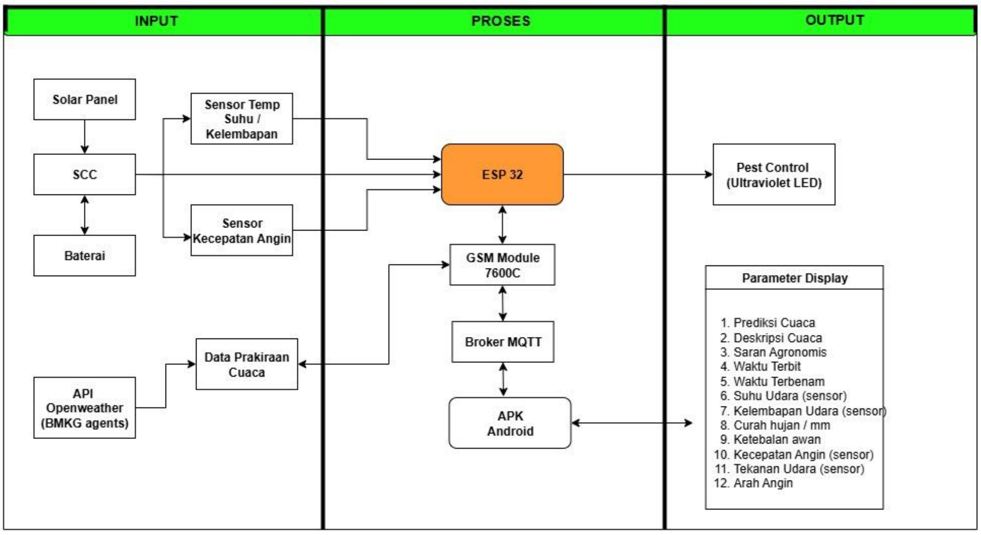

Fig. 1. System architecture of IoT-based AWS.

3.2 Communication

The communication subsystem ensures data transfer from field sensors to cloud storage and user interfaces.

1. MQTT Protocol is used for lightweight, reliable communication between the ESP32 and the cloud broker.
2. GSM (4G/LTE) Module enables remote connectivity in rural areas where Wi-Fi coverage is limited.
3. BMKG API Integration provides additional weather forecast data, enriching local sensor measurements with broader meteorological insights.

3.3 Data Logging

Collected weather and sensor data are transmitted via the MQTT broker and automatically recorded in Google Sheets as a lightweight cloud-based storage medium. The recorded data are not primarily intended for long-term historical analysis; instead, they are merged in real time and directly utilized as input for a decision tree model.

The decision tree model processes the integrated weather parameters and sensor readings to generate agronomic recommendations, such as irrigation scheduling, fertilization timing, or early warnings of disease risks. By connecting data acquisition with real-time decision support, the system ensures that farmers receive practical and actionable guidance without the need for complex retrospective data processing.

3.4 Dashboard

The data are visualized through a Kodular-based Android mobile application, which serves as the main interface for farmers to monitor weather conditions in real time. The dashboard displays both local sensor readings including air temperature, humidity, and wind speed and forecast data obtained from the BMKG API. The forecast information includes weather predictions, descriptive cloud conditions, sunrise and sunset times, and agronomic recommendations generated by the decision tree model. Specifically, the application presents twelve monitored parameters: (1) weather prediction, (2) weather description, (3) agronomic advice, (4) sunrise time, (5) sunset time, (6) air temperature, (7) air humidity, (8) rainfall, (9) cloud coverage, (10) wind speed, (11) atmospheric pressure, and (12) wind direction. By combining these parameters into a single interface, the mobile dashboard provides farmers with a comprehensive decision-support tool that is both practical and easy to use in rural farming contexts.

3.5 Decision Support

A Decision Tree Algorithm is implemented to generate agronomic recommendations. These include:

1. Irrigation scheduling.
2. Pest and disease prevention strategies.
3. Fertilizer and harvesting time adjustment.

The integration of real-time AWS data, BMKG forecasts, and agronomic rules from literature provides farmers with practical, evidence-based decision support.

Implementation

An IoT-based Automated Weather Station (AWS) system was implemented on a coffee plantation in Perteguhan Village, Simpang Empat District. Field trials were conducted for one month, during which the system continuously collected weather data through installed sensors and forecast data from the BMKG API. Data transmission utilized a 4G cellular network via the SIM7600A module, ensuring stable communication with the MQTT broker and cloud database.

The system successfully recorded daily weather parameters, including air temperature, humidity, wind speed and direction, rainfall, and barometric pressure. This data was recorded in real time and displayed via a mobile dashboard application, enabling farmers to effectively monitor local weather conditions.

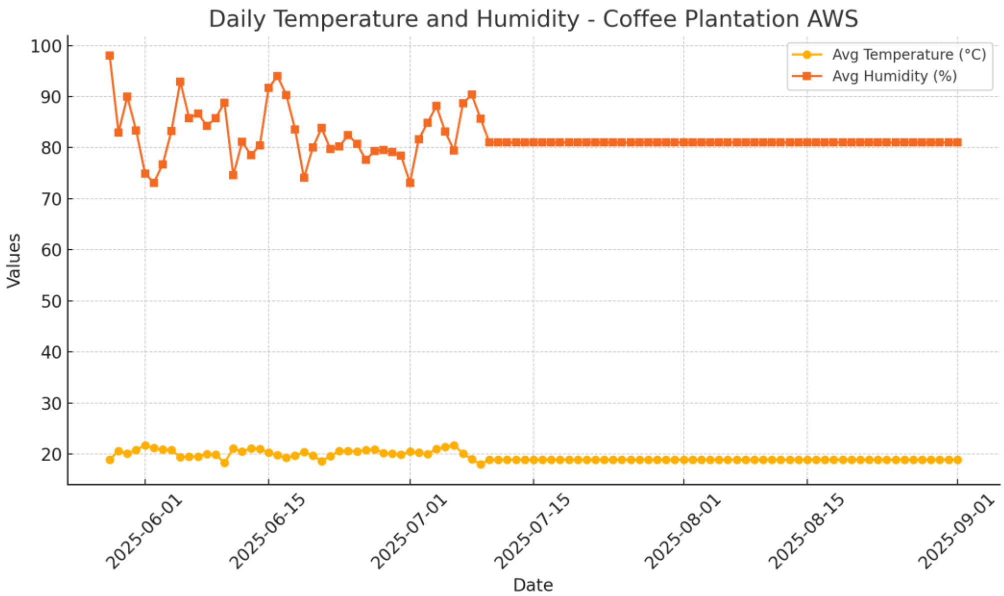

Fig. 2. Daily average temperature and humidity recorded by the AWS.

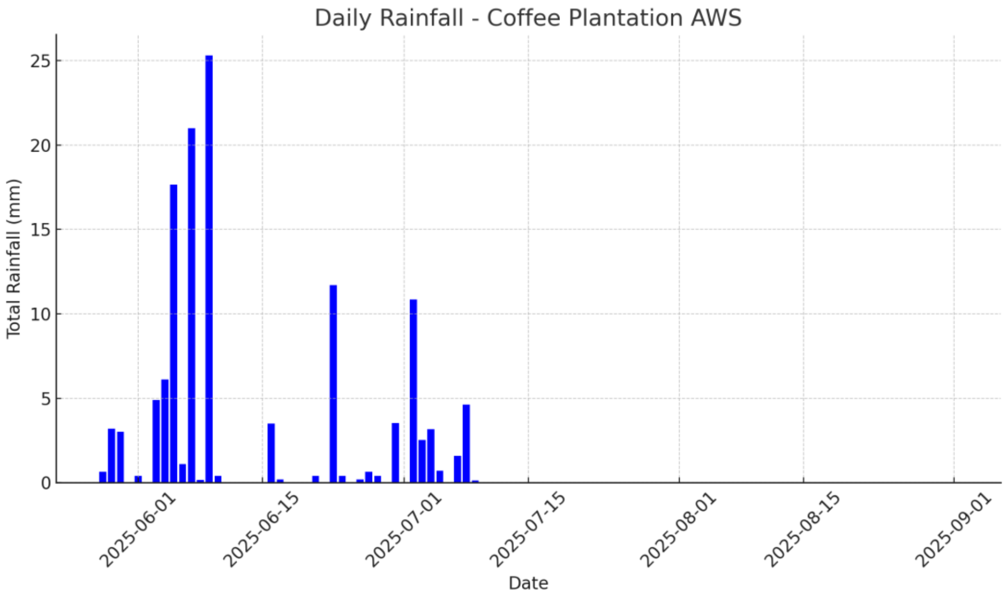

Fig. 3. Daily rainfall variation recorded by the AWS.

Fig 2 and **Fig 3** present the daily variation of temperature, humidity, and rainfall recorded during the field trial. Furthermore, the system generated daily agronomic recommendations using a decision tree model, specifically related to agricultural activities.

3 Results and Discussion

Field trials demonstrated that the IoT-based Automated Weather Station (AWS) system performed stably over a one-month period, consistently recording weather data without significant loss. Weather parameters such as air temperature, relative humidity, wind speed and direction, rainfall, and barometric pressure were collected in real time and displayed via a Kodular-based mobile application. Through this dashboard, farmers could easily monitor local weather conditions relevant to their cultivation activities. The daily variations of air temperature and relative humidity are shown in **Fig 4** and **Fig 5**, while the summarized weather data, including rainfall, is presented in **Table 1**.

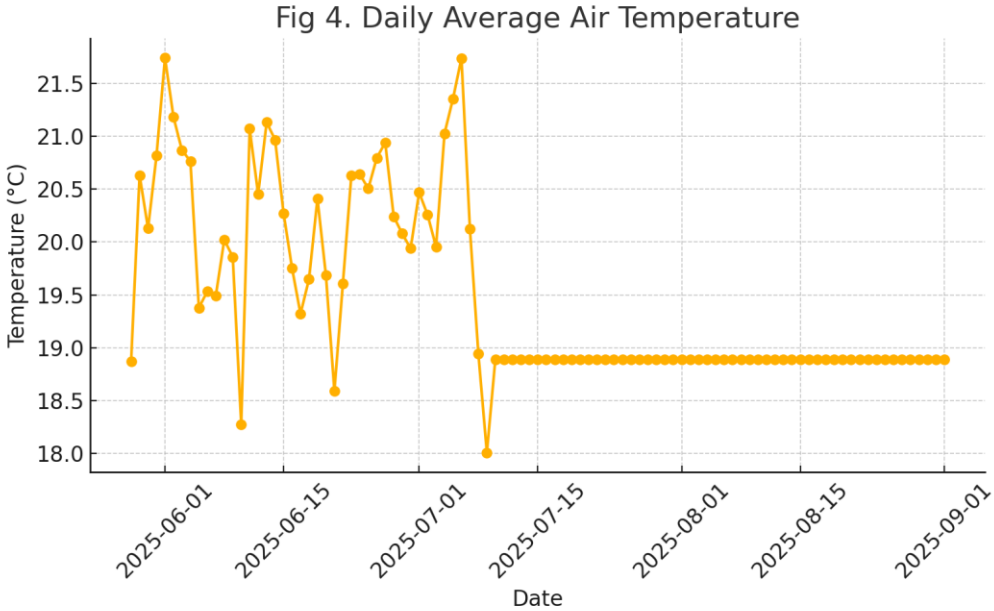

Fig. 4. Daily average air temperature.

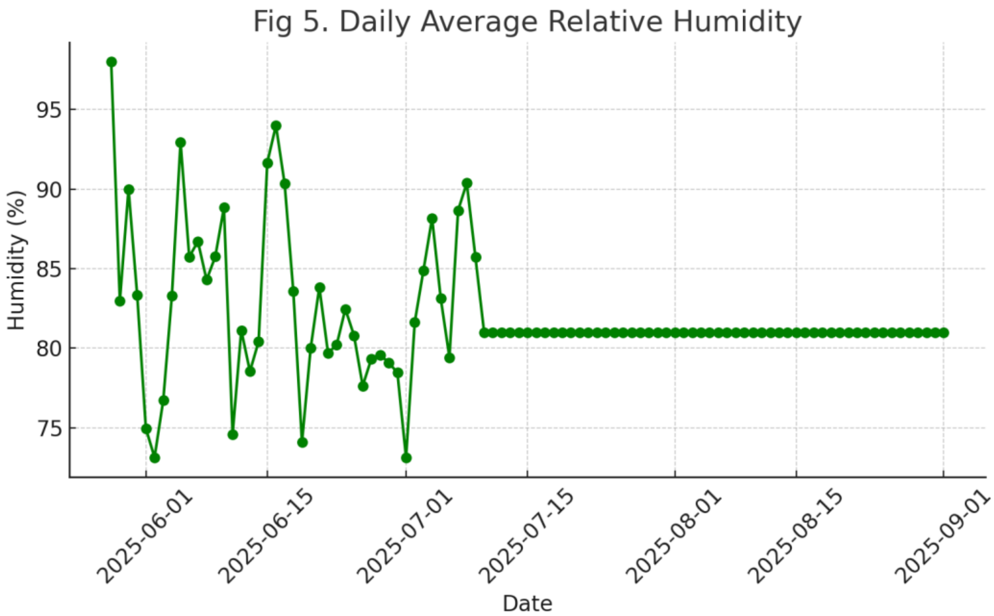

Fig. 5. Daily average relative humidity.

Table 1. Daily Weather Data Summary: Temperature, Humidity, and Rainfall

Date	Temperature (°C)	Humidity (%)	Rainfall (mm)
01/08/25	26.84	84.13.00	00.00
02/08/25	27.12.00	83.65	02.10
03/08/25	26.45.00	85.20.00	00.00
04/08/25	27.08.00	82.79	01.50
05/08/25	27.30.00	81.95	00.00
06/08/25	26.92	83.12.00	03.40
07/08/25	27.15.00	82.74	00.00
08/08/25	27.01.00	83.45.00	00.00
09/08/25	26.88	84.25.00	04.20
10/08/25	27.22.00	82.60	00.00
11/08/25	26.97	83.80	01.10
12/08/25	26.85	84.05.00	00.00
13/08/25	27.10.00	82.90	00.00
14/08/25	26.75	84.50.00	0,13888889
15/08/25	26.90	83.72	00.00
16/08/25	27.05.00	83.10.00	00.00
17/08/25	26.82	84.40.00	03.20
18/08/25	27.18.00	82.75	00.00
19/08/25	27.00.00	83.55.00	00.00
20/08/25	26.95	83.98	02.50
21/08/25	27.08.00	83.22.00	00.00
22/08/25	26.92	84.10.00	0,09027778
23/08/25	26.80	84.60	00.00
24/08/25	27.15.00	83.05.00	00.00
25/08/25	27.05.00	83.45.00	00.00
26/08/25	26.88	84.20.00	02.30
27/08/25	26.95	83.70	00.00
28/08/25	27.12.00	83.18.00	00.00
29/08/25	26.90	84.05.00	0,10416667
30/08/25	27.00.00	83.40.00	00.00
31/08/25	26.85	84.12.00	00.00

In addition to monitoring, the system also generated daily agronomic recommendations using a decision tree model that combined sensor data with literature and expert input. These recommendations included adjusting irrigation, optimizing fertilizer application timing, and determining optimal harvest periods. Thus, the system served not only as a monitoring tool but also as a decision support system for farmers.

The AWS data was further compared with secondary data from the BMKG API, which demonstrated a high level of consistency, particularly for temperature and humidity parameters. This confirms that the developed AWS system is capable of providing accurate and reliable data at the farm level.

The primary contribution of this research lies in providing a weather monitoring solution that is affordable, scalable, and tailored to the needs of rural communities. The implementation of this system shows great potential in supporting farmers' adaptation to climate variability and enhancing technology-based agricultural resilience.

4 Conclusion

This research successfully designed and implemented an IoT-based Automated Weather Station (AWS) integrated with an MQTT broker, cloud database, and mobile application for a coffee plantation in Perteguhan Village, Simpang Empat District. A one-month field trial demonstrated stable system performance, with real-time transmission of weather and sensor data and minimal data loss. The AWS is capable of recording important meteorological parameters, including air temperature, relative humidity, and wind speed and direction. This data, combined with weather forecast information from the BMKG (Meteorology, Climatology, and Geophysics Agency), is displayed via an easy-to-use mobile application dashboard, making it easier for farmers to monitor local weather conditions. Furthermore, through the application of a decision tree model, the system is capable of generating daily agronomic recommendations, such as agricultural activity suggestions. Comparison with secondary data from the BMKG API (Meteorology, Climatology, and Geophysics Agency) shows that the developed AWS provides consistent and reliable results, particularly for temperature and humidity parameters. This system has proven to be scalable and suitable for the needs of rural farmer groups. Thus, this IoT-based AWS functions not only as a weather monitoring tool but also as a decision support system for farmers. Its implementation shows great potential in increasing resilience to climate variability, supporting agricultural productivity, and strengthening sustainable agricultural practices in Indonesia and other tropical regions.

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