Development of a Solar-Powered Weather Monitoring System with IoT Integration for the Caraga Region, Philippines

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Abstract: *This study presents the design and implementation of a solar-powered, low-cost Automated Weather Station (AWS) for the Caraga Region, Philippines. The system measures solar radiation, wind speed, wind direction, and rainfall, using a Node-MCU ESP32 microcontroller and the Blynk platform for real-time data transmission. Four units were deployed across the region to assess performance in diverse conditions. Calibration and validation were conducted by comparing AWS data with that from a certified PAGASA station, using Root Mean Square Error (RMSE) and descriptive statistics. Results showed strong agreement, particularly in solar radiation and wind speed. The project demonstrates the potential of affordable, localized weather monitoring systems to support agriculture, disaster preparedness, and climate resilience in underserved areas.*

Keywords: Automated Weather Station (AWS); Internet of Things (IoT); Solar-Powered Monitoring; Low-Cost Weather System; ESP32 Microcontroller;

1. INTRODUCTION

In Philippines, over the past three decades, the frequency and severity of weather events have significantly increased, complicating weather prediction efforts [1]. Weather monitoring is crucial in various domains such as disaster monitoring [2], agriculture [3][4], climate research [5], and maritime [6]. Advancements in technology have transformed the technique for gathering and evaluating meteorological data, represented by Automated Weather Stations (AWS). AWS measures temperature, wind direction, speed, solar radiation, and other parameters that help in planning for operational activities.

Automated weather stations use a combination of sensors, microcontrollers, and communication technologies to track and provide meteorological data. They collect data automatically from various sensors and are processed by a microcontroller, which acts as both the data processor and communication interface. Weather data can be accessed remotely through Wi-Fi connectivity, which transfers the data to a cloud-based platform.

The Caraga Region in Mindanao, Philippines, features a tropical rainforest climate with abundant rainfall and warm temperatures. Residents who rely on weather conditions face significant challenges due to unpredictable weather patterns. This study aims to address these issues by designing and implementing an automated weather station that detects weather conditions and sends data to the internet using a Node-MCU ESP32. The proposed automated weather station is essential for modernizing weather monitoring systems, offering enhanced capabilities, real-time data transmission, and energy efficiency.

The study's scope was limited to the design and implementation of an automated weather station that monitors solar radiation, rain precipitation, wind speed, and wind direction. The system was deployed in three parts of the Caraga region, specifically Nasipit, del Norte, Brgy. Buhangin, Butuan City, Cabadbaran, Agusan del Norte, and Bayugan, Agusan del Sur.

2. METHODOLOGY

INPUT

- Review of existing AWS systems and literature
- Key weather parameters: solar radiation, wind speed/direction, precipitation

PROCESS

- Design and prototype of low-cost AWS
- Sensor integration with microcontroller and transmission modules
- Sensor calibration and lab testing
- Development of visualization tools
- Field deployment and real-time data logging
- Performance evaluation

OUTPUT

- Functional low-cost AWS measuring four parameters
- Real-time data from four sites
- Performance evaluation vs. standard instruments
- Support for local climate monitoring and planning

Fig. 1. Framework of the system.

Fig. 1 presents the study's framework divided into Input, Process, and Output. The Input includes a review of existing AWS systems and identifies key weather parameters to monitor. The Process covers the design, sensor integration, calibration, deployment in four Caraga locations, and real-time data transmission. The Output highlights the successful creation of a low-cost AWS, validated weather data collection, system evaluation, and recommendations for broader use in climate monitoring, agriculture, and disaster preparedness.

The study was conducted in four different locations, namely Nasipit, Agusan del Norte; Brgy. Buhangin, Butuan City; Cabadbaran City, Agusan del Norte; and Bayugan City, Agusan del Sur. These locations were strategically selected based on two criteria:

1. Geographical diversity, to capture varying microclimates and environmental conditions across the Caraga region.
2. Urban-rural representation, ensuring the system was tested in both developed and remote areas.

Automatic weather stations were fabricated with a height of 157 centimeters and deployed in different areas. This height was set to balance practical deployment, sensor accuracy, and safety. At 157 centimeters, the sensors were elevated enough to reduce interference from ground-level heat, splashes, and obstructions while remaining accessible for routine maintenance and inspection. Each station was composed of six primary components installed on a frame with vertical and horizontal axes. The system included a concrete base, sensors mounted at the top of the pole, and circuitry and batteries housed in a protective box. The sensor placement was designed to effectively capture weather information.

To ensure the accuracy and dependability of the low-cost automated weather station (LCAWS), the device was installed near a Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA)-certified weather station. This approach ensured that both stations were subjected to identical environmental conditions. Data from both stations were collected simultaneously over a set period under similar conditions. The measurements from LCAWS were compared to those from PAGASA station, which served as the reference standard. Statistical tools were used to assess the deviation for each measured parameter. This examination helped establish the performance of the low-cost sensors and guided any necessary calibration to improve their accuracy.

This diagram represents a solar-powered weather monitoring system using ESP32 microcontrollers and various environmental sensors.

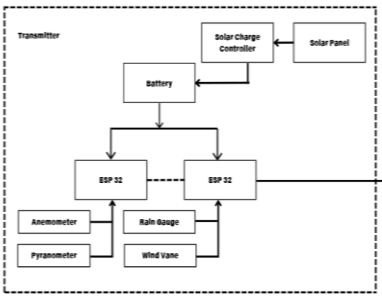

Fig. 2. System architecture of the system

Fig. 2 depicts the block diagram of the system comprising a power unit, control unit, sensing unit, and graphical user interface. It is a solar-powered monitoring system that measures specific parameters in a process, providing real-time information to the user. The system can transmit the collected data via the web, allowing remote access and monitoring through an internet-connected device.

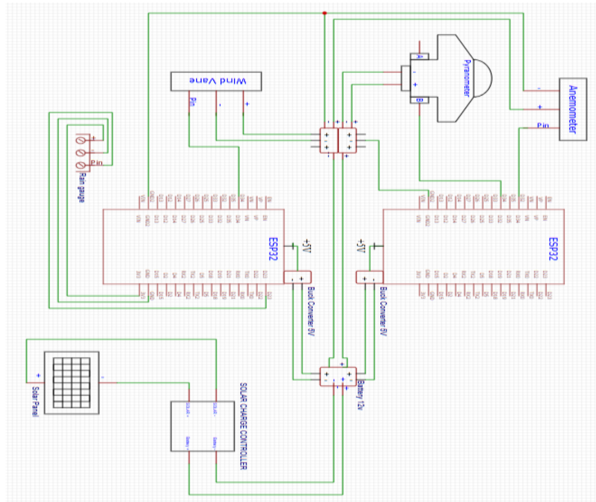

Fig. 3. Schematic diagram of the system

Fig. 3 illustrates the schematic diagram of a solar-powered weather monitoring system, which depicts the various components, their relationships, and describes their electrical connections.

The ESP32 microcontroller was responsible for processing sensor data and sending it for analysis. The power subsystem began with a solar panel connected to a solar charge controller that regulated the power flow to a rechargeable battery. The battery then supplied power to a buck converter, which reduced the voltage to the required level for the microcontroller. The microcontroller was linked to four weather sensors: a pyranometer for solar radiation, a wind vane for wind direction, an anemometer for wind speed, and a rain gauge for rainfall tracking.

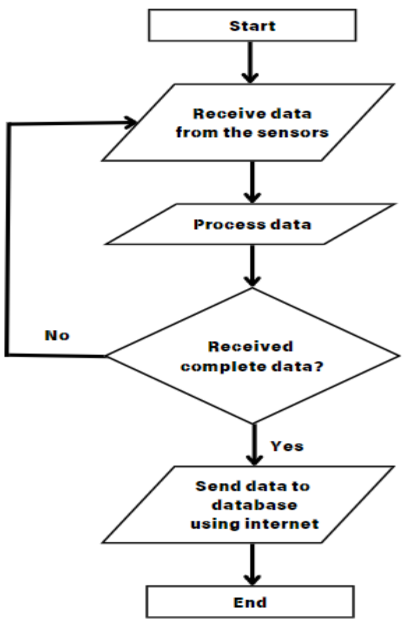

Fig. 4. Flowchart of the system

The system's control flow, shown in Fig. 4, began with an initialization procedure that validated the cloud connection and displayed the system's name. The sensing units then read and measured all the parameters and displayed the results using Blynk.

The Low-Cost Automated Weather Station (LCAWS) data collection and testing phase included fabrication costing, methodical deployment, and continuous monitoring at four strategically chosen locations around the Caraga Region. The system was configured to capture real-time environmental conditions such as wind speed and direction, solar radiation, and rainfall rate. The device utilized an Internet of Things (IoT) platform to transmit data every minute to a centralized cloud service via the Blynk software, enabling both real-time monitoring and historical data retrieval. Over a period of 30 days, the LCAWS operated continuously, documenting detailed environmental conditions and microclimatic variations.

To assess the accuracy and performance of the LCAWS, ts sensor data were compared with those from a PAGASA-certified station using Root Mean Square Error (RMSE), which measured the average deviation between the two datasets. Lower RMSE values indicated higher accuracy. Data collected from the test sites were processed using spreadsheet software and analyzed with descriptive statistics, including mean and standard deviation, to evaluate consistency and variability. This analysis also supported an assessment of the LCAWS's cost-effectiveness and reliability relative to commercial systems.

3. RESULT AND DISCUSSION

To ensure affordability and accessibility, the automated weather station was designed with cost efficiency as a top priority. Components were chosen based on both functional compatibility and cost-effectiveness (see Fig. 5), with an advantage for generic and commonly available parts. Table 1 shows the total cost in fabricating the LCAWS.

Fig. 5. Fabricated automated weather station

Table 1. Price list of the fabricated system

COMPONENTS	PRICE (Php)	NOTES
Pyranometer	3,822	Purchased
Wind Speed and Direction	1,742	Purchased
Rain Gauge	1,482	Purchased
ESP32 WROOM-32	300	Purchased
12 V Battery	500	Purchased
PCB	85	Purchased
Solar Panel	700	Pre-owned
Solar Charge Controller		
Circuit Box	100	Pre-owned
Solid Wires	80	Purchased
Buck Converter	138	Purchased
Square Tube Metal	450	Purchased
Screw	18	Purchased
TOTAL	**9,417**	(excluding pre-owned parts)

In weather applications, where precise environmental data was required for forecasting, research, and public safety, validating sensors was essential. This section involved comparing the output of the observer device (LCAWS) to that of a reliable reference (PAGASA station). Sensor validation employed methods to evaluate whether a new or alternative system functioned within acceptable boundaries. Additionally, proper sensor validation improved data confidence and ensured compatibility with a broader data network.

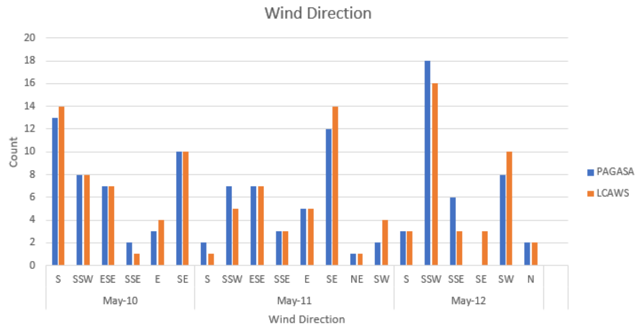

Fig. 6. Wind direction dataset comparison of the PAGASA station and LCAWS

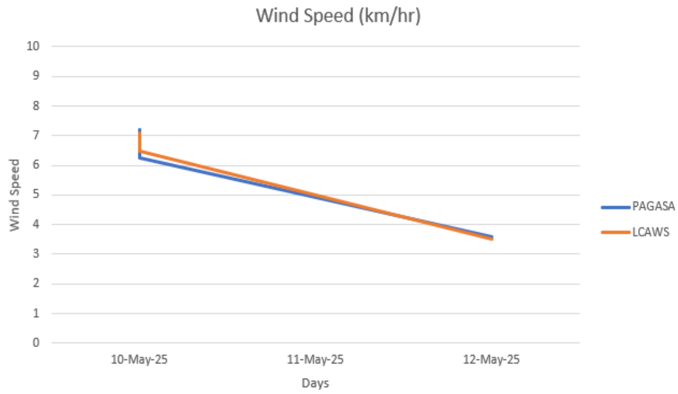

Fig. 7. Wind speed dataset comparison of the PAGASA station and LCAWS

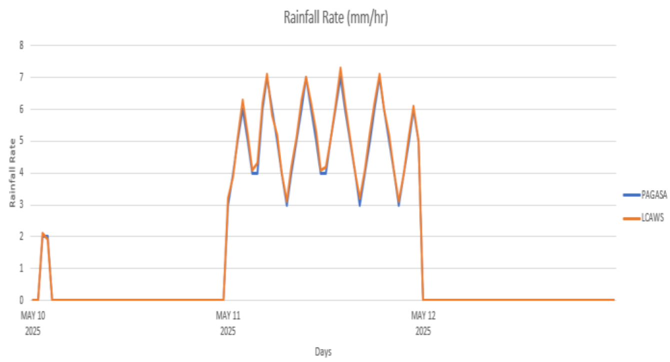

Fig. 8. Rainfall rate dataset comparison of the PAGASA station and LCAWS

The data seen in Fig. 6 to Fig. 9 represent the comparative performance analysis between PAGASA and the The fabricated LCAWS was tested across four meteorological parameters, and the data showed a generally good comparison with the PAGASA station. On day 1, the wind direction matched closely, with an accuracy of 97.5%, indicating strong alignment. Although the match slightly decreased on days 2 and 3, it still reflected an acceptable level of agreement. Wind speed comparisons revealed minimal root mean square error (RMSE) values, suggesting that the LCAWS data closely aligned with that of PAGASA. Solar radiation measurements also demonstrated good consistency, with RMSE values remaining within a small range. While the rainfall rate RMSE was low on day 1, it increased to 0.1725 on day 2, likely due to variations in rainfall detection thresholds. Overall, LCAWS delivered consistent readings that were comparable to PAGASA's, with slightly more variation in rainfall measurements.

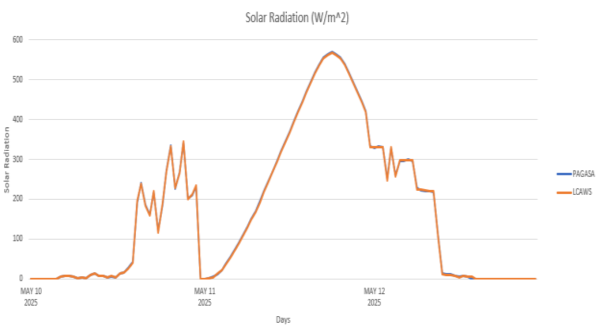

Fig. 9. Solar radiation dataset comparison of the PAGASA station and LCAWS

Before deployment, a thorough system test was conducted to ensure sensor precision, data accuracy, and logging reliability. The device was then deployed in four locations within the Caraga Region, Philippines: Nasipit, Agusan del Norte; Brgy. Buhangin, Butuan City; Cabadbaran City, Agusan del Norte; and Bayugan City, Agusan del Sur.

Location 1 (Nasipit) features relatively low hills and mild slopes where flooding and landslides are common occurrences. Location 2 (Buhangin), a barangay in Butuan City, is situated on the city's western edge, near the Agusan River. Location 3 (Cabadbaran) is a coastal municipality in the northeastern region of Mindanao. Location 4 (Bayugan) is a landlocked city, which implies there is no coastline.

The Blynk dashboard displays data from four sensors: solar radiation, wind speed and direction, and rain gauge, recorded every minute for 30 days. Location 3 had the highest solar radiation levels, with an average of 97.78 W/m^2 and a peak of 330 W/m^2. Locations 4 and 2 had lower average solar radiation levels, indicating cloud cover or shadowed conditions. Location 2 experienced the greatest rainfall variability, with an average rain rate of 1.13 mm/hr and a peak of 53.00 mm/hr. Locations 1 and 3 experienced dry weather. Wind speed statistics varied among locations, with Location 3 having the fastest average wind speed of 5.22 km/hr, while Location 1 had light winds. Wind gusts in Location 2 and Location 4 reached 12-15 km/hr, indicating temporary weather changes.

Location 3 is the most active site for solar exposure and wind activity, while location 2 is known for its rainy weather. These differences are crucial for determining the performance and environmental resilience of the deployed hardware system under various air conditions. Wind direction data from four monitoring stations shows distant patterns in prevailing wind behavior. Locations 1 and 2 have highly uniform wind direction, with over 99% of recorded data indicating NW winds.

Table 2. Wind speed, solar radiation, and rain rate data summary (1-month monitoring). Standard Deviation (SD), Minimum(Min), and Maximum(Max)

Measured Values	count	mean	SD	Min Value	Max Value
LOCATION 1: NASIPIT, AGUSAN DEL NORTE					
Wind Speed (km/hr)	2784	1.04	2.57	0	13
Solar Radiation (W/m^2)	2784	82.29	117.74	0	330
Rain Rate (mm/hr)	2784	0	0	0	0
LOCATION 2: BRGY. BUHANGIN, BUTUAN CITY					
Wind Speed (km/hr)	2880	0.24	1.35	0	12
Solar Radiation (W/m^2)	2880	14.33	36.03	0	232
Rain Rate (mm/hr)	2880	1.13	6.47	0	53
LOCATION 3: CABADBARAN CITY, AGUSAN DEL NORTE					
Wind Speed (km/hr)	2880	5.22	4.10	0	15
Solar Radiation (W/m^2)	2880	97.78	121.63	0	330
Rain Rate (mm/hr)	2880	0	0	0	0
LOCATION 4: BAYUGAN CITY, AGUSAN DEL SUR					
Wind Speed (km/hr)	2880	0.40	2.29	0	15
Solar Radiation (W/m^2)	2880	25.28	48.23	0	330
Rain Rate (mm/hr)	2880	0.20	1.68	0	16.68

Location 3 has a more diverse wind profile, with more occurrences from other directions, suggesting more complex local dynamics. Location 4 also experiences a variety of wind directions, with NW being the dominant direction. These locations are better suited for studies requiring directional wind diversity or evaluating sensor accuracy under variable wind input.

A comparative review of commercially available AWS was conducted when determining the best weather monitoring system to use. The survey evaluates units based on their cost, sensor capability, data transmission method, and power supply configuration. Table 4 compares AWS across different markets.

Table 3. Wind direction data summary (1-month monitoring)

direction	location 1	location 2	location 3	location 4
E	0	0	30	60
ENE	0	0	60	180
N	0	0	540	330
NW	2784	2820	1890	2250
S	0	0	120	0
SE	0	0	90	30
SN	0	0	60	0
SSE	0	0	90	0
W	0	0	0	30
WNW	0	60	0	0

Table 4. Comparison of the fabricated system against a commercial-grade system

Store	Price (php)	Link	Sensors	Iot	Power supply
Fabricated LCAWS	8,617		Wind Speed and Direction, Rain Rate, Solar Radiation	✓	Battery and Solar Panel
Scaled Instrument	106,035.41	https://tinyurl.com/hu7xjxcd	Wind Speed and Direction,Temperature ,Humidity, Solar Radiation	✗	5W Solar Panel

Prices varied considerably from ₱ 5,247 at alifetime.ph to ₱106,035.41 from Scaled Instruments. Mid-range units, such as those from Lazada and Trekkin, typically cost between ₱7,000 and ₱17,000 and include sensors for wind speed and direction, temperature, humidity, atmospheric pressure, and rainfall rate. Higher-priced models included additional features like UV radiation and light intensity sensors.

In terms of data transmission, the majority of the surveyed systems used IoT connectivity, which enabled real-time data streaming over wireless networks. This feature enables convenient remote access and is appropriate for areas with reliable internet facilities. Notably, the Scaled Instruments weather station employed a data logger that provided consistent data recording without relying on network availability, but at a significantly higher cost.

The power supply system in these devices also varies. Most products supported both battery and solar panel configurations, catering to a variety of deployment scenarios. The Fabricated LCAWS system, developed for this study, included a solar-powered solution to ensure autonomous and sustainable operation in remote or off-grid areas.

The Fabricated LCAWS, priced at ₱9,417, offer essential weather monitoring capabilities such as wind speed and direction, solar radiation, and rainfall rate, while also providing practical power and data solutions. Although it lacks some advanced sensors found in high-end systems, it meets core monitoring requirements at a lower cost, making it an ideal solution for cost-sensitive field deployments, particularly in geographically diverse areas like the Caraga Region.

4. CONCLUSION

The Low-Cost Weather Station (LCAW) was successfully designed, built, and deployed in four locations in the Caraga Region, Philippines. The system, costing ₱9,417, was built using affordable components and demonstrated consistent performance in recording weather conditions for 30 days. The data was logged every minute and communicated in real time via the Blynk IoT platform, demonstrating the technology's potential for continuous weather monitoring. The system was deployed in geographically diverse sires, revealing significant microclimatic variance. Location 3 had the highest average solar radiation and wind speed, while location 2 had the highest rainfall variability. The LCAWS demonstrated a competitive advantage compared to commercially available AWS models, providing equivalent sensor performance and operational autonomy at a quarter of the cost.

5. REFERENCES

[1] M. Nsabagwa, M. Byamukama, E. Kondela, and J. S. Otim, “Towards a robust and affordable Automatic Weather Station,” *Development Engineering*, vol. 4, p. 100040, Nov. 2018, doi: 10.1016/j.deveng.2018.100040. Available: https://doi.org/10.1016/j.deveng.2018.100040

[2] G. F. L. R. Bernardes, R. Ishibashi, A. A. S. Ivo, V. Rosset, and B. Y. L. Kimura, “Prototyping low-cost automatic weather stations for natural disaster monitoring,” *Digital Communications and Networks*, vol. 9, no. 4, pp. 941–956, May 2022, doi: 10.1016/j.dcan.2022.05.002. Available: https://doi.org/10.1016/j.dcan.2022.05.002

[3] S. Dandrifosse, A. Jago, J. P. Huart, V. Michaud, V. Planchon, and D. Rosillon, “Automatic quality control of weather data for timely decisions in agriculture,” *Smart Agricultural Technology*, vol. 8, p. 100445, Apr. 2024, doi: 10.1016/j.atech.2024.100445. Available: https://doi.org/10.1016/j.atech.2024.100445

[4] A. Faid, M. Sadik, and E. Sabir, “An agile AI and IoT-Augmented Smart Farming: a Cost-Effective cognitive weather station,” *Agriculture*, vol. 12, no. 1, p. 35, Dec. 2021, doi: 10.3390/agriculture12010035. Available: https://doi.org/10.3390/agriculture12010035

[5] W. Wang, S. Li, S. Guo, M. Ma, S. Feng, and L. Bao, “Benchmarking urban local weather with long-term monitoring compared with weather datasets from climate station and EnergyPlus weather (EPW) data,” *Energy Reports*, vol. 7, pp. 6501–6514, Oct. 2021, doi: 10.1016/j.egyr.2021.09.108. Available: https://doi.org/10.1016/j.egyr.2021.09.108

[6] P. Kalvelis, D. Mazzei, M. Biviano, and C. Stylios, “PortWeather: A Lightweight Onboard Solution for Real-Time Weather Prediction,” *Sensors*, *20*(11), 3181. https://doi.org/10.3390/s2011318

[7] R. Weerasinghe, A. Pannila, M. Jayananda, and D. Sonnadara, *“Construction of an Automated Weather Station for Ground Level Weather Measurements,”* 2011,

https://www.semanticscholar.org/paper/Construction-of-an-Automated-Weather-Station-for-Weerasinghe-Pannila/f273213cb12f1b73c16b3b1ac8973f5391059462

[8] M. Farhat, M. Abdul-Niby, M. Abdullah, and A. Nazzal, "A Low-Cost Automated Weather Station for Real Time Local Measurements," In *Engineering, Technology & Applied Science Research* (Vols. 7–7, Issue 3, pp. 1615–1618), 2017, https://www.etasr.com

[9] K. Ioannou, D. Karampatzakis, P. Amanatidis, V. Aggelopoulos, and I. Karmiris, "Low-Cost automatic weather stations in the internet of things," *Information*, vol. 12, no. 4, p. 146, Mar. 2021, doi: 10.3390/info12040146. Available: https://doi.org/10.3390/info12040146

[10] L. J. Olatomiwa, and U. S. Adikwu, "Design and Construction of a Low Cost Digital Weather Station," *AU Journal of Technology*, *16*(2), 2012, http://www.assumptionjournal.au.edu/index.php/AUJournalofTechnology/article/download/1363/1197

[11] S. N. Essiane and B. G. O. Essama, "Development of a micro weather station using Arduino and Internet of Things," *Physics Education*, vol. 57, no. 1, p. 015005, Oct. 2021, doi: 10.1088/1361-6552/ac2670. Available: https://doi.org/10.1088/1361-6552/ac2670

[12] "Caraga Region: Brief Profile." Available: https://caraga.deped.gov.ph/caraga-region-brief-profile/. [Accessed: Oct. 24, 2024]

[13] R.M. Weerasinghe, et al, "Construction of an Automated Weather Station for Ground Level Weather Measurements," *Annual Transactions of IESL*, Sri-Lanka, 450-455, 2011.

[14] World Meteorological Organization. (2018). *Guide to instruments and methods of observation; Volume III—Observing systems*. https://community.wmo.int/activity-areas/imop/wmo-no_8

[15] E. B. Sevandal, M. F. T. Menque, L. M. Dagsa, A. D. B. Balamad, and E. R. B. Sajonia, "Real-time IoT-based Motorcycle Accident Detection and Alert System," *Int. Exch. Innov. Conf. Eng. Sci.*, vol. 10, pp. 494–499, 2024, doi: 10.5109/7323306.

[16] A. Jones, B. Smith, and C.Taylor, "Automatic weather stations data acquisition," *Journal of Meteorological Systems and Technologies*, 12(4), 78-90, 2021.

[17] L. Brown, D. White, and S. Green, "Automatic weather stations data acquisition" *International Journal of Meteorological Technology*, 5(2), 45-56, 2010

[18] *"Hardware and sensor technology in AWOS,"* International *Research Journal of Engineering and Technology*, 7(5), 1203-1210, 2020.

[19] "Hardware and sensor technology in AWOS," Electrical *and Electronics Engineering: An International Journal*, 2(3), 45-53, 2013.

[20] M. Van den Broeke, et al, "Antarctic radiation balance," *Journal of Geophysical Research*, 109, D09103, *2015*, https://doi.org/10.1029/2003JD004161

[21] C. J. T. Niog, R. N. Mendoza, L. M. Dagsa, and J. C. Martinez, "IoT-based climate control system for cultivation of oyster mushroom (Pleurotus ostreatus) fruiting bag," *Int. Exch. Innov. Conf. Eng. Sci.*, vol. 10, pp. 252–259, 2024, doi: 10.5109/7323271.

[22] M. Van den Broeke, et al, "Comparison of radiation *measurements* in Antarctica," *Journal of Geophysical Research*, 109, D09103, 2016, https://doi.org/10.1029/2003JD004161

[23] L. S. Pereira, I. Cordery, and I. Iacovides, "*Improving* water resources management in Spain: Recent developments and future challenges," *Water Resources Management*, 29(12), 4261-4276, 2015, https://doi.org/10.1007/s11269-015-1084-2

[24] S. Beguería, S. M. Vicente-Serrano, and J. I. López-Moreno, "Meteorological drought assessment in Spain: A review of the methods and results," *Theoretical and Applied Climatology*, 136(3-4), 1699-1713, 2019, https://doi.org/10.1007/s00704-018-2592-1

[25] N. B. Guttman, "Statistical and hydrological analyses of the relationships between rainfall and surface water runoff," *Journal of Hydrology*, 220(1-2), 139-154, 1999, https://doi.org/10.1016/S0022-1694(99)00014-4

[26] S. M. Vicente-Serrano, J. I. López-Moreno, S. Beguería, and C. Azorín-Molina, "Overview of meteorological networks in Spain: Current status and future perspectives," *Climate Research*, 81(3), 325-340, 2022.

[27] D. R. Legates, and T. L. DeLiberty, "Overview of meteorological networks in Spain," *Journal of Climatology and Meteorology*, 7(3), 120-135, 2010.

[28] C. Bridge, *"Assessing the quality of automatic weather station observations from an external provider for data assimilation purposes (Bureau Research Report No. 089),"* Bureau of Meteorology, 2024, http://www.bom.gov.au/research/publications/researchreports/BRR-089.pdf

[29] D. J. B. Felias, D. P. Mondea, J. T. Dellosa, and R. N. Mendoza, "Design and development of an Internet of Things (IoT)-based Air Quality Monitoring for Libjo Mining Corporation," Int. Exch. Innov. Conf. Eng. Sci., vol. 10, pp. 365–370, 2024, doi: 10.5109/7323287

[31] U.S. Department of Energy, "Automatic weather stations." Available: https://www.science.gov/topicpages/a/automatic+weather+stations.html. [Accessed: Oct. 26, 2024]

[32] L. Ahmad, R. H. Kanth, S. Parvaze, and S. S. Mahdi, "Automatic *weather* station," in *Springer eBooks*, 2017, pp. 83–87. doi: 10.1007/978-3-319-69185-5_12. Available: https://doi.org/10.1007/978-3-319-691/ (accessed 16.03.03).