Journal of Advanced Research in Applied Sciences and Engineering Technology 63, Issue 2 (2026) 137-147

Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage: https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

Simple and Low-Cost Ground Level Ozone Measurement System Based on Internet of Things

Irmansyah[1,*], Ananda Thalia[1], Husin Alatas[2], Sitti Yani[2], Ardian Arif Setiawan[1], Rofiqul Umam[3], Hirotaka Takahashi[4,5,6]

1 Applied Physics Division, Department of Physics, IPB University, Kabupaten Bogor, Jawa Barat 16680, Indonesia
2 Theoretical Physics Division, Department of Physics, IPB University, Kabupaten Bogor, Jawa Barat 16680, Indonesia
3 Institute of Life and Environmental Sciences, University of Tsukuba, Tsukuba, Ibaraki 305-8577, Japan
4 Department of Design and Data Science, Research Center for Space Science, Tokyo City University, Setagaya City, Tokyo 158-8557, Japan
5 Institute for Cosmic Ray Research (ICRR), The University of Tokyo, Bunkyo City, Tokyo 113-8654, Japan
6 Earthquake Research Institute, The University of Tokyo, Tokyo, Bunkyo City, Tokyo 113-8654, Japan

ABSTRACT

Air quality monitoring in Indonesia is still not optimal owing to the lack of ambient air quality monitoring stations. Air quality in Indonesia is expressed by the air pollution status index (ISPU). Ozone is one of the parameters with the highest intensity at ambient air quality monitoring stations which is one of the parameters of ISPU. This study aims to design an ambient air ozone concentration monitoring device connected to a wireless network using economical components. This system uses the MQ131 sensor, DHT22 sensor, STM32 Blue Pill microcontroller, and Lora module, which is equipped with a power supply and protector, and displays monitoring results that provide an overview and additional information related to the air quality of the monitoring location on the website. The designed monitoring device can record ambient air ozone levels at the monitoring location with an average value of 20.33 µg/m^3 with an average percent error of 2.34%. The ISPU value obtained during the measurement was 8, and the ISPU status was categorized as good.

Keywords:

Air quality; Internet of things; Ozone; Website; ISPU

1. Introduction

Air is a fundamental component for supporting life on our planet. The composition of the atmosphere extends the life expectancy of all organisms inhabiting Earth. Breathing contaminated air can lead to dangerous diseases, such as coronary disease (CHD), Chronic Obstructive Pulmonary Disease (COPD), lung cancer, stroke, and heart disease. Over an extended period, the consequences of inadequate air quality result in elevated temperatures and global climate alterations [1-3]. Air quality in Indonesia is described by the Air Pollution Status Index (ISPU), a unitless number that describes the ambient air quality at a particular location based on its impact on human health, aesthetic value, and other living things [4]. One of the ISPU parameters is ozone, which reflects the

* *Corresponding author.*
E-mail address: irmansyah@apps.ipb.ac.id

https://doi.org/10.37934/araset.63.2.137147

ambient air quality [5,6]. Ozone is produced naturally in the stratosphere 10–50 km above the Earth's surface and becomes the Earth's protective layer from harmful ultraviolet rays emitted by the sun. In the troposphere, which is at an altitude of 0–10 km above the Earth's surface, O_3 becomes an air pollutant and harms public health and the environment [7]. The effects of O_3 on human health include reduced lung function, respiratory system irritation and asthma. High O_3 concentrations also affect plants and are recognized as phytotoxic and a threat to forests, plants, and vegetation [8,9].

IoT, with its capacity to put regular objects to the web, has become a fundamental innovation of the 21st century, empowering consistent communication between individuals, forms, and things through low-cost computing, cloud, enormous information, analytics, and versatile advances. IoT has been applied in several fields, including the manufacture of Liquid Viscosity Measurement Devices [10] and air quality measurement using ozone parameters [5,11-18]. Benammar *et al.,* used the Waspmote board and Zigbee to send data [16]. Tian *et al.,* use Zigbee to send data from the node to the local server (Raspberry Pi) then from the local server sent to the internet using a mobile network [17]. A device proposed by Dineshkumar *et al.,* tracked the absence of O_3, SO_2, CO, and particulate matter in the air using Arduino. The data transmitted to the cloud system were retrieved using an Arduino Wi-Fi module [5]. These studies used expensive, less effective and efficient microcontrollers and data communication components, which resulted in high production costs.

Based on this problem, this study designed an ambient air ozone concentration monitoring device to send data via a wireless network with economical components equipped with a power supply and tool protector. ISPU calculation results for ozone parameters read by this tool can be monitored directly on the website provided.

2. Methodology

2.1 Node Sensors Design

The sensor node was a unit used to collect data consisting of an STM32 Blue Pill microcontroller, DHT22 sensor, MQ131 sensor, Lora transceiver module, and a power supply consisting of two batteries, a 1N4007 diode, charger module, 5 V voltage regulator, and solar panel. The design of the sensor node consists of hardware integration, as shown in Figure 1. Programming in the Arduino IDE software was performed to obtain data in the form of ozone concentrations in the air detected in SI units (µg/m^3). The sensor node protector was designed using SolidWorks software.

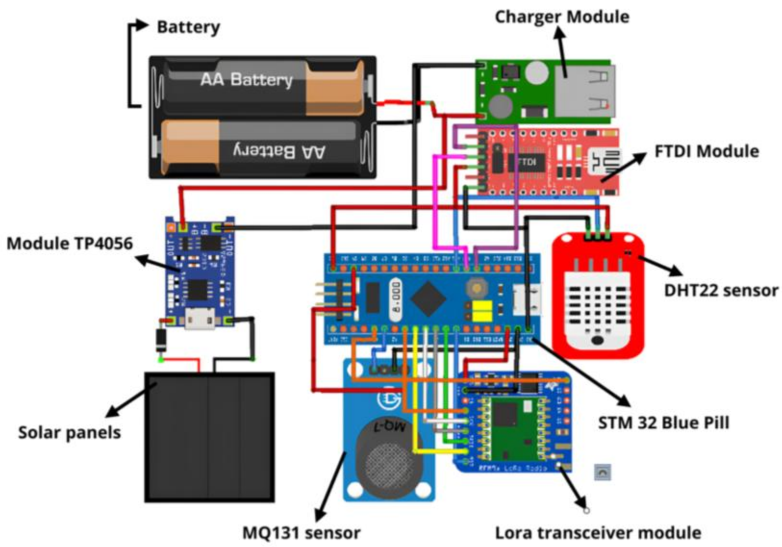

Fig. 1. Node sensors circuit

2.2 Website Design

The website displays an overview and additional information about air quality in the monitored area. First, a website display design will be created using Figma software. The website program will then be created using the PHP programming language in the Visual Studio Code. The information displayed on the website is a graph of the relationship between the measured ozone concentration value against time and the ISPU value and category. The ISPU was calculated using Eq. (1):

$$I = \frac{(I_a - I_b)}{(X_a - X_b)} (X_X - X_b) + I_b, \quad (1)$$

with I = Calculated ISPU, I_a = Upper limit of ISPU, I_b = Lower limit of ISPU, X_a = Upper limit of ambient concentration (μg/m^3), X_b = Lower limit of ambient concentration (μg/m^3) and X_x = Calculated ambient concentration (μg/m^3)

ISPU is classified into five categories, which are listed in Table 1 along with their respective implications.

Table 1
Ozone concentration breakpoint for ISPU

ISPU	Concentration (μg/m$^{3)}$	Category	Description
1 – 50	120	Good	No Effect
51 – 100	235	Medium	Air quality levels are still acceptable for human, animal and plant health.
101 – 200	400	Unhealthy	The level of air quality that is detrimental to humans, animals and plants.
201 – 300	800	very unhealthy	The level of air quality that may increase the health risk in some segments of the exposed population.
≥ 300	1000	Dangerous	Air quality levels that could seriously harm the health of the population and require urgent treatment.

2.3 Sending Data from Node to Server

The data obtained from the node are sent to Antares Telkom's Lora gateway via the Lora transceiver module, which plays a key role in the data transmission process. Furthermore, the data appear on the Antares platform. The ozone concentration data in the ambient air were then obtained from the Antares platform and processed on the server using Eq. (1) to obtain the ISPU values. The server pack used was XAMPP, which uses Apache as a web server.

2.4 Implementation

The device was implemented by placing a node at the data collection location. Ideally, the measurement was performed in open air at an open angle of 120° to the obstacle, a minimum of two meters from the ground, and a minimum distance of 20 m from the emission source. Next, the sensor node data were sent so that they could be displayed on website (Figure 2).

Fig. 2. Tool workflow

3. Results and Discussion

The ambient air ozone monitoring device consisted of an MQ131 sensor with a 5 V power supply connected to the PA1 analogue pin of the STM32 Blue Pill microcontroller. Then, there is a DHT22 as a temperature and humidity sensor powered by 3.3 V and connected to pin PA11 on the microcontroller. In addition, the Lora module is powered by 3.3 V with the NSS pin of the Lora module connected to pin PA4 on the microcontroller, the RST pin connected to pin PB0, pin DIO0 to PA3, pin DIO1 to PA0, pin MISO to PA6, and pin MOSI to PA7, and pin SCK to PA5. Soldering was performed on the components used for the power supply, whereas the other components were mounted on a breadboard and connected using jumper cables.

The STM32 Blue Pill microcontroller was chosen because of its lower price, smaller size, and more suitable specifications than similar microcontrollers, as mentioned in the STM32F103xB Data Sheet and Linne [19]. Wireless data communication uses Lora because it is very suitable for IoT applications owing to its wide range and low power usage. In addition, utilizing Antares Telkom's Lorawan network, the cost of purchasing a Lora gateway can be eliminated. The DHT22 sensor was selected as the temperature and humidity sensor because it has a more comprehensive measurement range and higher accuracy than the DHT11 sensor. Meanwhile, the MQ131 sensor was chosen as the ambient air ozone level sensor because it has a wide measurement range, is suitable for measuring low-concentration ozone levels, is relatively affordable, durable, and lightweight.

Solar panels were chosen as the power supply of the device so that the device had an independent power supply and used environmentally friendly alternative energy. When there is sunlight, one 5 WP solar panel is used to supply power to the device, along with recharging two batteries that will be the source of electricity in the absence of sunlight. The solar panel is connected to a 5 V voltage regulator so that the voltage entering the microcontroller can be stabilized, and it is also connected to the charger module to recharge the battery.

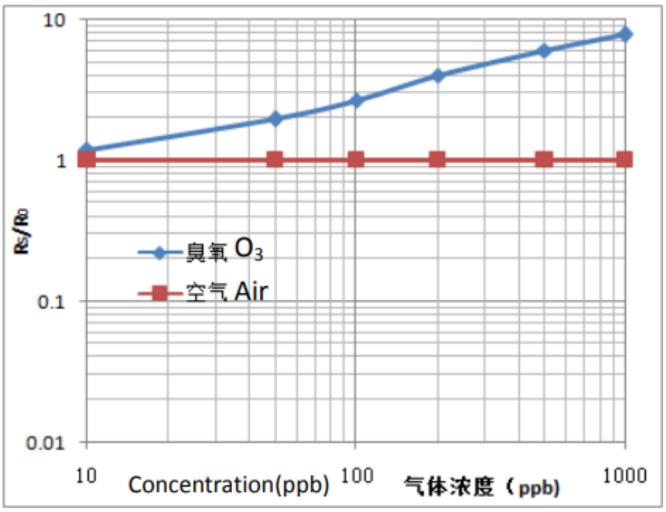

Fig. 3. Sensitivity curve of MQ131 sensors (ZWETC 2014)

Before installing the device at the data collection location, calibration was performed on the sensors used. The MQ131 sensor was calibrated by comparing its readings with those in the datasheet. Figure 3 shows the sensitivity curve of the MQ131 sensor obtained from the datasheet. R0 is the resistance value of the sensor when the air is clean, and Rs is the resistance value of the sensor at a specific ozone concentration. At the same time, kppm is the ozone concentration at the calibration time based on a comparison tool, namely, the Handle Portable Ozone Detector Meter Digital Temperature Humidity Sensor. It can be seen that the curve in Figure 2 is a logarithmic graph between Rs/R0 and ozone concentration in ppb. Furthermore, for easier processing, the y- and x-axes were inverted. Then, with nonlinear regression y = ax + b, the values of a and b were obtained.

The device was programmed to take and send data every 15 minutes. The results of the MQ131 sensor readings were processed using the program on the Arduino IDE to produce ozone levels in SI units, namely μg/m3, and then processed using Eq. (1) on the server to produce the ISPU value. The reading results from the DHT22 sensor were also processed using the program on the Arduino IDE to produce temperature data in degrees Celsius (°C) and humidity in percent (%). The processed data from the sensor were then sent to Antares Telkom's Lora gateway through the Lora transceiver module. The data were then retrieved and processed on the server to be displayed on the website.

3.1 Tool Protector Design

The tool protector shown in Figure 4 was designed using SolidWorks software. It is made of a polylactic acid (PLA) filament and is printed using a 3D printer. The tool protector was printed separately in sections and then joined using screws. The gaps were patched using waterproof glue and coated with waterproof paint to prevent water from entering and damaging the components. The tool protector was coated with white paint to prevent heat absorption by the tool protector.

The overall length of the protector is 21.5 cm, and the tube through which the air flows is 7.5 cm in diameter. The length and width of the electronic box were 9.4 cm and 7 cm, respectively. A hole at the bottom of the electronic box connects the sensing part of the sensor to the microcontroller. The case was designed to protect electronics from rainwater while allowing air to flow through the sensor.

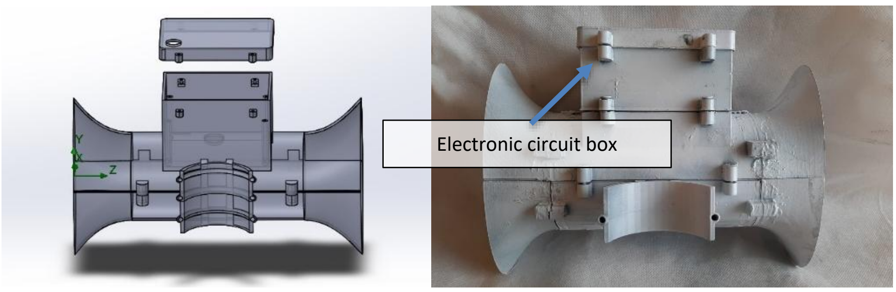

Fig. 4. Tool protector

3.2 Website Design

The website was programmed using the PHP, CSS, and JavaScript programming languages. A map displaying the station position on the website page is shown in Figure 5. The map on the website was created using the Leaflet library, a free JavaScript-based website mapping library. If a station is clicked, it will display information in the form of the station name, station location, last data value obtained in the form of the ISPU value, ozone content, temperature, humidity, and ISPU status.

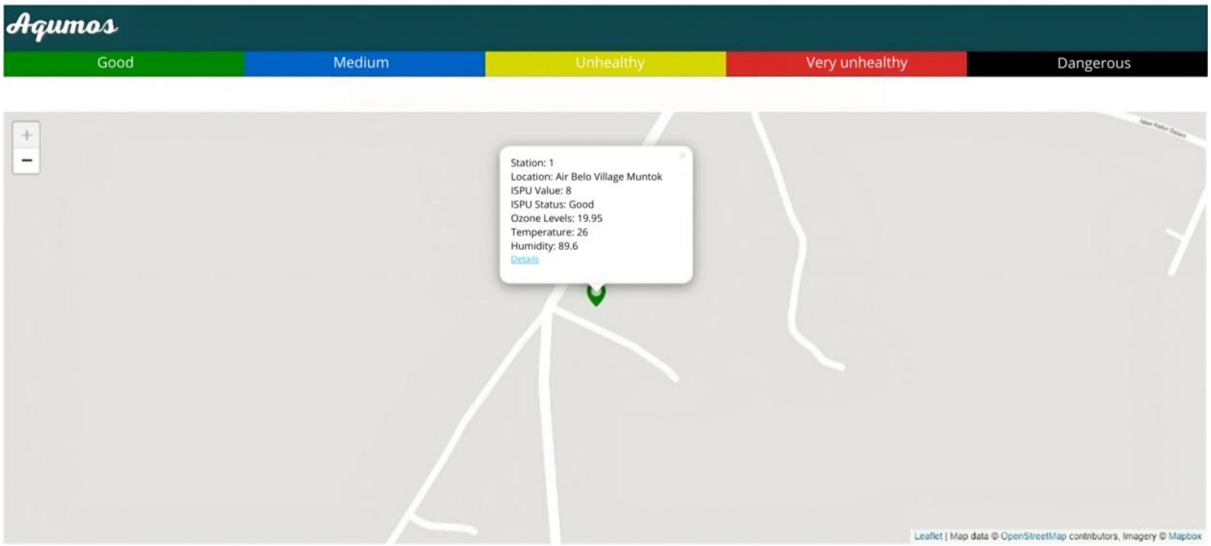

Fig. 5. A map displaying the station position on the website page

The overall data loaded in the graphs are detailed in the following section. Figure 6 show the detailed section on the website. The detailed section contains a graph of ozone levels against time, station name, station location, date of the data displayed, ISPU value, ISPU category, ozone level, temperature, humidity, and additional information, namely, recommended activities and the impact of the ISPU category. Graphs on the website were created using the Highcharts library to create graphs on JavaScript-based websites.

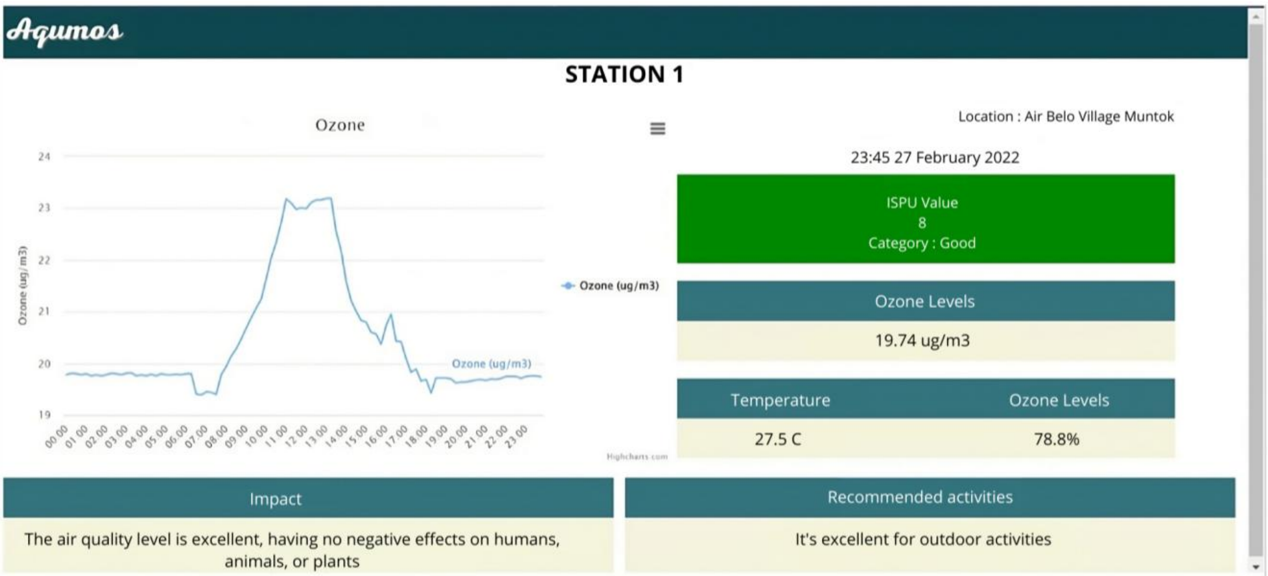

Fig. 6. Display the Details section of the website

3.3 Device Testing

The tests conducted in Muntok City, West Bangka Regency, Indonesia. The device was installed 2 m above the ground and 20.16 m from the road. This location fulfils two of the three requirements for an ideal monitoring location: at least 2 m above the ground and at least 20 m from the emission source. However, the requirement to be placed in air with an open angle of 120° to avoid obstructions was not met because there were trees and houses at the monitoring location. Figure 7 shows the documentation of the installation site.

Fig. 7. Tool installation

Tool testing was carried out for seven days with a range of data collection every 15 minutes. Six hundred thirty-seven data were collected and 35 failed to be sent to the gateway. Thus, the percentage of data sent was 94.79%, with the distance between the monitoring point and the Lora gateway being 5 km. Failure to send data can be caused by radio frequency interference or collision of data packets when the data transmission is dense.

The solar panel array used was sufficient to power the device. The power supply comes directly from a solar panel in the presence of sunlight. In the absence of sunlight, the power is supplied by two rechargeable 3.7 V 3400 mAh batteries that can supply power for a maximum of 18 h 46 min. When the sun is shining brightly, the voltage generated by the solar panel without additional components, when measured using a multimetre, is 9–10 V. When the weather was sunny and cloudy, the measured voltage was 8 V. When the weather is cloudy, the measured voltage is approximately 6–7 V. Without sunlight, the measured voltage is approximately 0.01 - 0.02 V.

3.4 Ambient Air Ozone Level Measurement

Ambient air ozone levels were measured using a pre-calibrated MQ131 sensor. The MQ131 measurement results were compared with the Handle Portable Ozone Detector Meter Digital Temperature Humidity Sensor to determine the percentage error of the obtained data. Data are presented in ppm units because the comparison tool uses these units. Twenty data points were used to calculate the percent error (Table 2). The most significant percentage error was 11.11%, with an average of 2.34%.

Table 2
Percentage measurement error of ambient air ozone levels

Data	Ozone levels MQ131 (ppm)	Ozone levels Portable Ozone Detector (ppm)	Error (%)
1	0.011	0.012	8.33
2	0.011	0.011	0
3	0.011	0.011	0
4	0.011	0.011	0
5	0.011	0.010	10.00
6	0.010	0.011	9.09
7	0.010	0.010	0
8	0.011	0.011	0
9	0.011	0.011	0
10	0.011	0.012	8.33
11	0.011	0.011	0
12	0.011	0.011	0
13	0.011	0.011	0
14	0.011	0.011	0
15	0.010	0.010	0
16	0.010	0.010	0
17	0.010	0.010	0
18	0.010	0.009	11.11
19	0.011	0.011	0
20	0.011	0.011	0
Average percentage error			2.34

Figure 8 shows a graph of the results of measuring the ambient air ozone levels for seven days. The results show that the average ambient air ozone level at the test location was 20.33 µg/m3. This value was processed using Eq. (1), an ISPU value of 8 was obtained, and the ISPU status was categorized as good. The minimum ozone level is 19.38 µg/m^3, and the maximum is 23.20µg/m^3. Ozone is a secondary pollutant formed by photochemical reactions, and its changes are influenced by many factors, such as its precursors and meteorological factors [20-22]. The intensity of solar radiation, as shown in Figure 8, influences ozone level fluctuations.

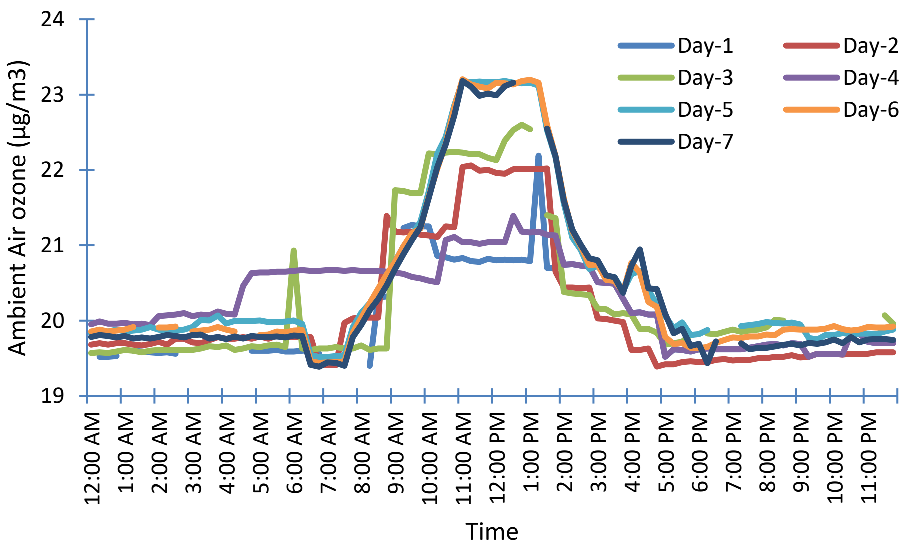

Fig. 8. Ambient air ozone levels for 7 days of measurement

Figure 9 shows a graph of the average measurement results of ambient air ozone levels for seven days. Based on the data obtained, it is known that the maximum ozone levels occur in the time range between 11:00 AM and 01:00 PM. From 05:00 PM to 07:00 AM, the ozone concentration tended to stabilize.

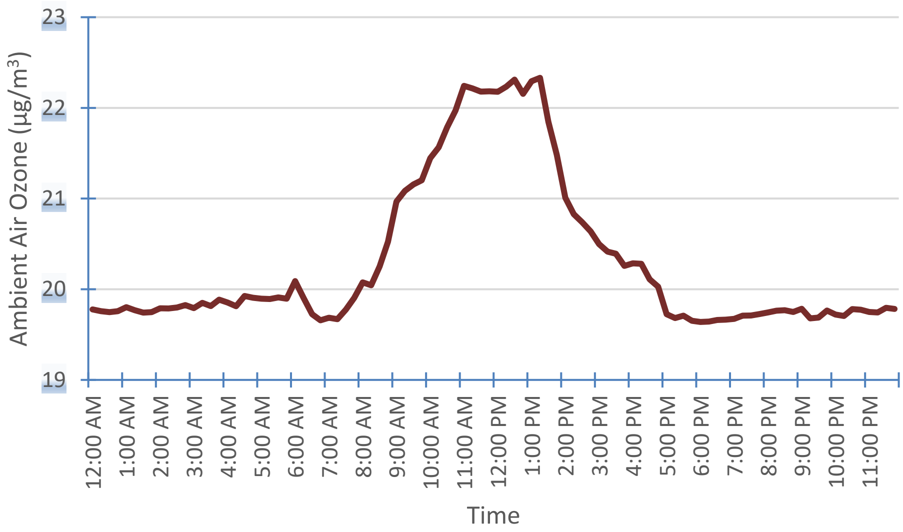

Fig. 9. Average ambient air ozone level measurement

4. Conclusions

An instrument for monitoring the concentration of ambient air ozone has been created that can send data via a wireless network in real-time with economical components and has an independent power supply from solar panels that is sufficient to run the device and is equipped with a tool protector. In addition, it can display monitoring results on a website in the form of an overview and additional information related to air quality at the monitoring location. Based on the equipment testing conducted, it was found that at the test location, the average ambient air ozone level was 20.33 µg/m^3 with an average per cent error of 2.34%, which is ISPU 8, and the ISPU status is in a suitable category.

Acknowledgement
This research was not funded by any grant.

References
[1] Mani, Geetha, Joshi Kumar Viswanadhapalli, and P. Sriramalakshmi. "AI powered IoT based real-time air pollution monitoring and forecasting." In *Journal of Physics: Conference Series*, vol. 2115, no. 1, p. 012016. IOP Publishing, 2021. https://doi.org/10.1088/1742-6596/2115/1/012016

[2] Jo, JunHo, ByungWan Jo, JungHoon Kim, SungJun Kim, and WoonYong Han. "Development of an IoT-based indoor air quality monitoring platform." *Journal of Sensors* 2020, no. 1 (2020): 8749764. https://doi.org/10.1155/2020/8749764

[3] Malleswari, S. M. S. D., and T. Krishna Mohana. "Air pollution monitoring system using IoT devices." *Materials Today: Proceedings* 51 (2022): 1147-1150. https://doi.org/10.1016/j.matpr.2021.07.114

[4] Mashuri, Agus Alwi, and Nely Zulfa. "Air Quality Monitoring System in Semarang City Based on IoT." *Rekayasa: Jurnal Penerapan Teknologi dan Pembelajaran* 18, no. 2 (2021): 44-51.

[5] Dineshkumar, T., V. Suresh Babu, Pachaivannan Partheeban, and R. Puviarasi. "Air quality monitoring system based on IoT." In *Journal of Physics: Conference Series*, vol. 1964, no. 6, p. 062081. IOP Publishing, 2021. https://doi.org/10.1088/1742-6596/1964/6/062081

[6] Buelvas, Julio, Danny Múnera, Diana P. Tobón V, Johnny Aguirre, and Natalia Gaviria. "Data quality in IoT-based air quality monitoring systems: a systematic mapping study." *Water, Air, & Soil Pollution* 234, no. 4 (2023): 248. https://doi.org/10.1007/s11270-023-06127-9

[7] Feenstra, Brandon, Vasileios Papapostolou, Berj Der Boghossian, David Cocker, and Andrea Polidori. "Development of a network of accurate ozone sensing nodes for parallel monitoring in a site relocation study." *Sensors* 20, no. 1 (2019): 16. https://doi.org/10.3390/s20010016

[8] Wang, Tao, Likun Xue, Peter Brimblecombe, Yun Fat Lam, Li Li, and Li Zhang. "Ozone pollution in China: A review of concentrations, meteorological influences, chemical precursors, and effects." *Science of the Total Environment* 575 (2017): 1582-1596. https://doi.org/10.1016/j.scitotenv.2016.10.081

[9] Anitha, M., and Lakshmi Sutha Kumar. "Development of an IoT-enabled air pollution monitoring and air purifier system." *MAPAN* 38, no. 3 (2023): 669-688. https://doi.org/10.1007/s12647-023-00660-y

[10] De Medeiros, Helton Pierre Lucena, and Gustavo Girão. "An IoT-based air quality monitoring platform." In *2020 IEEE international smart cities conference (ISC2)*, pp. 1-6. IEEE, 2020. https://doi.org/10.1109/ISC251055.2020.9239070

[11] Hadi, Herry Sufyan, Putri Yeni Aisyah, Syamsul Arifin, Ahmad Fauzan Adziimaa, and Arief Abdurrakhman. "Fluid viscosity measuring instrument with Internet of Things (IoT) based rotary method." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 92, no. 1 (2022): 65-89. https://doi.org/10.37934/arfmts.92.1.6589

[12] García, Laura, Antonio-Javier Garcia-Sanchez, Rafael Asorey-Cacheda, Joan Garcia-Haro, and Claudia-Liliana Zúñiga-Cañón. "Smart air quality monitoring IoT-based infrastructure for industrial environments." *Sensors* 22, no. 23 (2022): 9221. https://doi.org/10.3390/s22239221

[13] Setiawan, F. N., and I. Kustiawan. "IoT based air quality monitoring." In *IOP Conference Series: Materials Science and Engineering*, vol. 384, no. 1, p. 012008. IOP Publishing, 2018. https://doi.org/10.1088/1757-899X/384/1/012008

[14] Soares, Carlos, Eliza Gomes, Fabiano Dahlke, C. D. Rolt, Patricia Plentz, Mario Dantas, and Vildes Scussel. "Use of IoT to real-time monitoring of storage silo and ozone gas fungal decontamination strategy." *International Journal of Computers and Applications* 175, no. 16 (2020): 1-7. https://doi.org/10.5120/ijca2020920663

[15] Novianta, Muhammad Andang, and Cyrilla Indri Parwati. "Application of Internet of Things (IoT) on air pollution monitoring database system." In *E3S Web of Conferences*, vol. 125, p. 25005. EDP Sciences, 2019. https://doi.org/10.1051/e3sconf/201912525005

[16] Benammar, Mohieddine A., Sabbir HM Ahmad, Abderrazak Abdaoui, Hasan Tariq, Farid Touati, Mohammed Al-Hitmi, and Damiano Crescini. "A smart rig for calibration of gas sensor nodes." *Sensors* 20, no. 8 (2020): 2341. https://doi.org/10.3390/s20082341

[17] Tian, Bin, Kun Mean Hou, Xunxing Diao, Hongling Shi, Haiying Zhou, and Wei Wang. "Environment-adaptive calibration system for outdoor low-cost electrochemical gas sensors." *IEEE Access* 7 (2019): 62592-62605. https://doi.org/10.1109/ACCESS.2019.2916826

[18] Saparullah, Rizky, Jesi Pebralia, and Lucky Zaehir Maulana. "Internet of Things (IoT) and Arduino IDE as a Smart Water Quality Control for Monitoring in Catfish Ponds." *International Journal of Hydrological and Environmental for Sustainability* 3, no. 1 (2024): 48-56. https://doi.org/10.58524/ijhes.v3i1.415

[19] Linne B. "Simulating High-Speed Objects with LEDs." *Fort Belvoir: ARL-TN*. (2020).

[20] Chen, Yuanchen, Lu Zang, Jinyuan Chen, Da Xu, Defei Yao, and Meirong Zhao. "Characteristics of ambient ozone (O 3) pollution and health risks in Zhejiang Province." *Environmental Science and Pollution Research* 24 (2017): 27436-27444. https://doi.org/10.1007/s11356-017-0339-x

[21] Riedel, Theran P., Glenn M. Wolfe, Kenten T. Danas, Jessica B. Gilman, William C. Kuster, Daniel M. Bon, Alexander Vlasenko *et al.,* "An MCM modeling study of nitryl chloride (ClNO 2) impacts on oxidation, ozone production and nitrogen oxide partitioning in polluted continental outflow." *Atmospheric Chemistry and Physics* 14, no. 8 (2014): 3789-3800. https://doi.org/10.5194/acp-14-3789-2014

[22] Ou, Jiamin, Zhijiong Huang, Zbigniew Klimont, Guanglin Jia, Shaohui Zhang, Cheng Li, Jing Meng *et al.,* "Role of export industries on ozone pollution and its precursors in China." *Nature Communications* 11, no. 1 (2020): 5492. https://doi.org/10.1038/s41467-020-19035-x