International Journal on Advanced Science Engineering Information Technology

Vol.13 (2023) No. 6
ISSN: 2088-5334

Research in Electronic Multi-Sensor Accuracy in the Implementation of Soil Fertility Monitoring System Using LoRA

Wahyu Pamungkas [a,*], Mas Aly Afandi [a], Sarah Astiti [a], I Ketut Agung Enriko [a,b], Anis Sirwan Zukhrufi [c], Rahmat Hardian Putra [c], Rohmat [c]

[a] *Institut Teknologi Telkom Purwokerto, Indonesia*
[b] *PT Telkom Indonesia, Indonesia*
[c] *Department of Agriculture and Food Security, Banyumas Regency, Indonesia*
*Corresponding author: *wahyu@ittelkom-pwt.ac.id*

***Abstract*—The use of electronic sensors to track the nutrients in the soil is an interesting tool for farmers. This has led to the sale of many different kinds of electronic sensors with different levels of accuracy. The accuracy of this electronic sensor was figured out by comparing the results of the sensor's measurements with the results of lab tests done in different ways. This study compares the accuracy of electronic devices used to measure soil nutrients like nitrogen, phosphorus, potassium, electrical conductivity, water pH, and humidity to measurements made in the lab using the ICP-OES (Inductively coupled plasma-optical emission spectroscopy) method. We used three electronic sensors and a transmission system based on LoRA (Long Range) to measure the nutrients in the soil and put the results on our website. The similarities between electronic sensors and laboratory test parameters include the standard deviation, accuracy value, and correlation test between sensors and from the sensors to laboratory test results. The standard deviation parameter test showed a big value between the electronic sensor and the lab test results. However, none of the three used electronic sensors had a standard deviation number that differed greatly from the others. Except for the pH value of the soil, the electronic sensor's accuracy tests for the other five parameters were not very good compared to the lab tests. Also, the sensor correlation test showed a high correlation, while the correlation test between sensor data and lab test results showed a low correlation.**

***Keywords*—Electronic sensors; soil nutrients; accuracy; standard deviation; correlation; LoRA**

Manuscript received 5 Apr. 2023; revised 31 Oct. 2023; accepted 30 Nov. 2023. Date of publication 31 Dec. 2023.

I. INTRODUCTION

Soil fertility refers to the ability of a soil to support plant growth. Fertile soil contains all the essential nutrients that plants need to grow and develop in the right proportions and in a form that is available for plants. Soil fertility is determined by a combination of factors, including the presence of essential nutrients, the soil's pH, and the soil's structure and composition. Soil fertility can be improved by adding nutrients and other amendments, adjusting the pH of the soil, and practicing good soil management techniques. Soil fertility is important in agriculture, as it is essential for producing healthy and productive crops [1]. In addition to soil fertility, soil moisture is also known in the agricultural sector. Soil moisture refers to the amount of water present in the soil. This can be expressed as a percentage of the soil's total water-holding capacity or as the water per unit volume of soil. Soil moisture is an essential factor in agriculture, as it affects the growth and development of plants. It is also an important consideration in environmental studies, as it can affect the movement of water and nutrients through the soil and into groundwater. Soil moisture is typically measured using specialized instruments, such as capacitance [2] or resistance sensors [3].

Soil moisture is a necessary component of a soil's three-phase system, which consists of soil minerals (solids), water, and air [4]. Consequently, soil moisture content considerably impacts the engineering [5], agronomic, geological, ecological, biological, and hydrological properties of soil mass. A soil's mechanical properties, including consistency, compatibility, cracking, swelling, shrinkage, and density, depend on its moisture content. In addition, it plays a crucial role in plant growth, natural ecosystem organization, and biodiversity. In agriculture, crop production requires the application of adequate and timely moisture for irrigation, depending on the soil moisture–plant environment [6].

Several parameters are commonly used to measure soil moisture, including water content, soil water potential, and soil moisture tension [7]. Water content refers to the amount of water in the soil, expressed as a percentage of the soil's total water-holding capacity. On the other hand, soil water potential refers to the energy state of the water in the soil and is typically expressed in units of pressure. Soil moisture tension is the amount of force that must be applied to the soil to extract water from it and is typically expressed in units of pressure per unit area. These parameters can be measured using specialized instruments, such as a tensiometer [8] or a time domain reflectometer (TDR) [9].

Farmers in developing countries, such as Indonesia, are equipped with a set of instruments called PUTS (Paddy Soil Test Device)[10] that can measure the levels of nitrogen, phosphorus, and potassium (NPK) in the soil to determine the level of soil fertility in a certain area. This instrument set does not display results in terms of amount but is rather color relative to the reference color. Another method farmers in Indonesia use to evaluate the degree of soil fertility is through the results of measurements from the soil fertility laboratory, which can take up to one week or even one month and is expensive. The soil fertility laboratory uses the Kjeldahl method to measure nitrogen levels [11], while to obtain phosphorus and potassium levels, it uses the inductively coupled plasma-optical emission spectroscopy (ICP-OES) method [12]. The Kjeldahl method is a common technique used to measure the nitrogen content of a sample. This method involves digesting the sample with a mixture of sulfuric and hydrochloric acids, which converts the nitrogen in the sample into ammonium sulfate. The ammonium sulfate is then distilled and titrated with a standardized base solution, and the concentration of nitrogen in the sample is determined based on the amount of base required to neutralize the ammonium sulfate. The Kjeldahl method is simple and reliable but requires specialized equipment and trained personnel. ICP-OES uses optical spectroscopy to measure the concentrations of elements in a sample. The method involves heating the sample using inductively coupled plasma, which produces bright light that is rich in electromagnetic radiation. This light is then passed through a monochromator, which separates the light into its various wavelengths. The light is then detected by a sensitive detector, which measures the intensity of the light at each wavelength. By analyzing the intensity of the light at different wavelengths, the concentration of different elements in the sample can be determined with high accuracy.

In recent years, electronic sensors to detect soil fertility have been widely used in Indonesia [13]–[16]. This method of measuring soil fertility using electronic sensors has results that are obtained more quickly than using soil fertility laboratory measurement methods or measurement kits from the Indonesian government. The market's most commonly used soil moisture sensors are the TDR soil moisture sensor and the frequency domain reflectometer (FDR) soil moisture sensor [17]. TDR and FDR are used in electronic sensors to detect NPK parameters in soil. Both technologies rely on the principle of reflectometry, which involves sending a pulse of electromagnetic radiation into a material and measuring the reflection of the pulse from the material. In the case of these technologies, electromagnetic radiation is typically in the form of radio waves or microwaves, and the material being measured is the soil. TDR and FDR sensors are commonly used in agriculture to measure the moisture content of soil, as well as other physical and chemical properties of soil. They can also be used to measure the concentrations of NPK in soil, although they may not be as accurate or precise as other methods, such as ICP-OES, used by the soil fertility laboratory.

This paper compares the accuracy of two techniques for evaluating soil fertility using electronic sensors and soil fertility laboratory test results. In addition, it describes the significance of this work to the development of a soil fertility monitoring system based on long-range (LoRA) technology and is displayed on the website. The monitoring of soil fertility was carried out using LoRA technology in a number of earlier studies that other researchers had carried out; however, these earlier studies did not display the results of a comparative analysis with the results of soil fertility measurements that had been carried out in the soil fertility laboratory. We analyzed the standard deviation parameters, a correlation test between the electronic sensors used, and the results of soil fertility laboratory tests on a total of seven sensor output parameters: pH, soil moisture, NPK, electric conductivity, and temperature. An examination of the LoRA communication system planning carried out in the Banyumas area of Indonesia is the next contribution of the research we present here.

Related works that have been done used LoRA or LoRA WAN technology as a communication medium to transmit data from electronic sensors [13], [18]–[23]. In addition, some papers specifically review research classifications regarding LoRA technology in various applications in all fields [24]. The next paper examines the application of LoRA in agriculture, including a mechanism for integrating all sensors and equipment whose data would be transmitted via LoRA. Research conducted by [25] presents a decision support system (DSS) for optimizing crop yield and improving sustainability in agriculture. The DSS includes three units: an intelligent sensor module, a smart irrigation system, and a controlled fertilizer module. The sensor module includes various sensors for measuring temperature, humidity, nutrient levels, soil moisture, conductivity, and pH. The data from these sensors are transmitted to the cloud using the LoRa communication protocol and can be accessed remotely through an Android application. This study does not focus on measuring the accuracy of electronic sensor results but only on DSS design.

Research results that are similar to those that have been done in this paper are in research [13]. This research describes a system for measuring and controlling the levels of NPK in soil to improve crop yield in Indonesia. The system includes fertilizers and soil moisture sensors with an automatic flushing system to provide real-time measurement and uses an Antares LR-ESP201 board and low-power WAN LoRa at a frequency of 920–923 MHz to transmit data to the cloud. The Internet of Things (IoT) can access and display the data on an Android smartphone. The results show that the system allows users to monitor and control soil content and fertilization and ensure effective watering on a farm. However, this study does not discuss how to define the accuracy of the NPK sensor or compare NPK sensor measurements with other measurement methods.

Much attention has also been paid to studies that concentrate on planning LoRA networks [26]–[28]. In research, [29] investigate the effects of shadowing on LoRa WAN links and analyze the performance in terms of packet loss ratio for different physical layer settings. The results show significant differences in performance when shadowing is considered, significantly impacting the expected performance. However, these studies focused only on designing LoRA networks without being implemented in an applied communication system using LoRA technology.

It is possible to conclude, after conducting a review of several earlier studies on the topic of LoRA WAN and electronic sensors measuring soil fertility as the research theme, that there has been no research discussing the accuracy of using electronic sensors in comparison to laboratory-based soil fertility measurements utilizing different methods. This finding is based on the fact that no previous studies on this research theme exist.

This paper is organized into five sections. The following section addresses the most recent research that correlates with and contrasts the work presented in the paper. In addition, the proposed technique consists of three sub-sections: planning the LoRA communication network in the Banyumas Regency of Indonesia, designing electronic sensors for detecting soil nutrients, and designing websites and user interfaces. In Chapter IV, analysis and discussion will be presented, including an analysis of the overall results of the implementation of the soil nutrient detection and monitoring system, the results of the LoRA wide area network (WAN) network planning, the results of electronic sensor tests in terms of standard deviation, consistency tests, and correlation tests between sensors, sensor results, and soil lab test results. This section also discusses the website design results in the SimoRA website. In addition, the ultimate conclusions of the research are presented in the concluding section.

II. Materials and Method

In this section, we develop three categories of research methodologies. The first section describes planning for a LoRa WAN network, the second examines electronic soil sensors, and the third describes web design and user interface planning.

A. LoRA Wireless Planning and Configuration

LoRa is a wireless network connected to the IoT platform, which is connected to the Internet with sensors or gateways (digital objects) without human intervention and thus requires low cost and low maintenance. LoRa is categorized as a low-power wide area network communication system in the form of a wireless network (wireless transmission) developed by chirp spread spectrum technology. This technology mimics the communication of animals, such as dolphins and bats, and it is claimed to be able to withstand interference and transmissions received at long distances.

The LoRa network is connected to an IoT platform that is connected to the Internet with sensors or gateways and operates at a frequency of 915 MHz in Indonesia. The IoT is associated with a future Internet concept that allows every object to become part of the Internet. The IoT enables interconnections between mobile and sensing devices, which are equipped with microcontrollers that can record information across platforms and communicate with each other and devices with users.

In this study, the LoRA network was installed in the Banyumas Regency in Indonesia, with the LoRA gateway positioned at one station on the Telkom Institute of Technology, Purwokerto campus. We analyzed and planned the LoRA WAN network to cover nodes in the form of electronic soil-fertility sensors placed in agricultural areas of the Banyumas Regency. Because it operates at 915 MHz, the LoRA network can be categorized as a microwave that propagates under line of sight (LOS) and non-line of sight (NLOS) conditions. We used the Longley–Rice Irregular Terrain propagation model, which is useful over the frequency range of 20 MHz to 20 GHz [30]. This propagation model was chosen because of the contours of the Banyumas area, which has hilly areas, plains, and highlands. In general, microwave propagation, where the transmitter side is on the Telkom Institute of Technology campus, Purwokerto, will be subject to path loss, shadowing, and multipath fading, as seen in Fig.1.

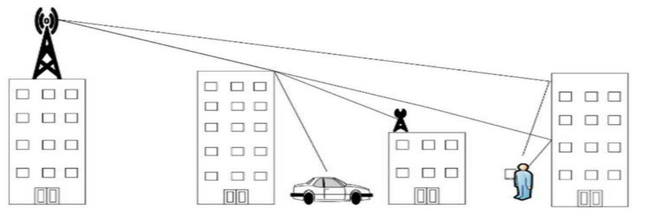

Fig. 1 Model propagation for LoRA communications with path loss, shadowing, and multipath [31]

If in an Line of sight (LOS) state, then the following formula can be used to derive the free-space LOS parameter:

$$PL(dB) = 32.5 + 20Log_{10}(f) + 20Log_{10}(d) \quad (1)$$

where f is the frequency used in MHz and d is the distance between transmitter and node receiver LoRA in Km. In LoRA network propagation conditions where shadowing effects are present, the following formula is used to calculate path loss:

$$PL(d)\,(dB) = \bar{PL}(d_0) + 10\pi Log\frac{d}{d_0} + \chi_\sigma \quad (2)$$

where $\bar{PL}(d_0)$ denotes the average large-scale path loss (in dB) at a distance d, and χ_σ is a zero mean Gaussian (normal) distributed random variable (in dB) with standard deviation σ also in dB. In the case of multipath fading between the transmitter and receiver, the signal will be distributed in accordance with Rayleigh and Rician distributions. If the received signal is mostly from an NLOS condition, the Rayleigh distribution will apply; however, if there is a single dominating LOS path in a multipath situation, the Rician distribution will apply. The parameter probability density function of Rayleigh fading can be determined using the following formula:

$$Pdf_{Ray} = \frac{r}{\sigma^2}exp\left(-\frac{r^2}{2\sigma^2}\right),\ r \geq 0 \quad (3)$$

If the Rician distribution occurs, the probability density function would be as follows:

$$Pdf_{Ric} = \frac{r}{\sigma^2}\left(-\frac{r^2 + K^2}{2\sigma^2}\right) I_0\left(\frac{Kr}{\sigma^2}\right),\ r \geq 0,\ K \geq 0 \tag{4}$$

where r is the amplitude of the envelope signal, σ is the standard deviation, K is the coefficient reflection of the channel, and I_0 is Bessel function at first kind zero order.

The IoT forms a network of physical objects embedded with sensors, software, and other technologies. Every IoT device works by using a set of rules to exchange data between electronic devices, where devices can work together; there are specific IoT protocols that devices use to communicate wirelessly. This protocol is critical to the IoT technology stack and enables communication and interaction between sensors, devices, gateways, servers, and user applications. This research monitors soil nutrient sensors with LoRa connectivity monitored through Antares as an IoT platform, as seen in Fig.2.

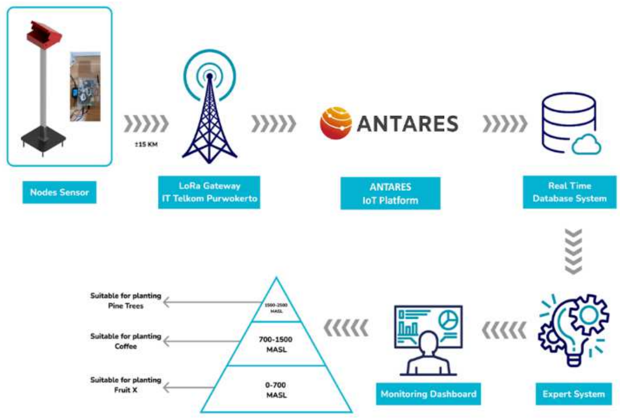

Fig. 2 Network configuration between the LoRA WAN and the Antares platform

B. Design Electronic Sensor

In this study, we used a seven-in-one soil fertility sensor to measure the parameters of NPK, water, pH, temperature, and soil moisture. We used three sensors of the same brand and type. The sensor was then connected to the Arduino UNO microcontroller, which sends the sensor reading output via LoRA. The hardware system in this research consists of four main elements. The first element is a sensor soil tester, the second is Modbus RTU RS485, the third is Arduino Uno as the main controller, and the last is the LoRa shield.

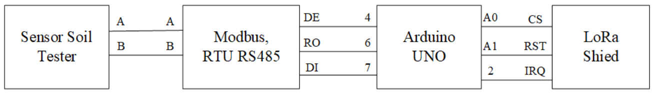

Fig. 3 Wiring diagram of hardware used

Fig.3 depicts the hardware wiring diagram that was carried out. Sensor soil testers utilize communication protocols such as RS485. Fig. 3 shows that the sensor soil tester sends its measurement output to Modbus RS485. Modbus will convert the data from the measurements into a serial protocol. Because Arduino is unable to read the RS485 protocol, this step must be completed. After the data have been transformed into their serial form, they will eventually be transmitted to the IoT platform.

As a form of hardware validation, the research in argument uses standard deviation, correlation, and consistency sensors. The value of the standard deviation can be calculated, which demonstrates that the sensor reading is accurate. By performing a correlation calculation between the sensors, one may demonstrate that each sensor will produce the same value while measuring the same object. In addition, consistency values demonstrate that the sensors produce the same value regardless of the time taken. The formula for calculating standard deviation is Eq. 5, while the formula for calculating correlation is Eq. 6.

$$\sigma = \sqrt{\frac{\sum (x_i - \mu)^2}{N}} \tag{5}$$

$$r = \frac{\Sigma\left(x_i - \bar{x}\right)\left(y_i - \bar{y}\right)}{\left(\sqrt{\Sigma\left(x_i - \bar{x}\right)^2 \left(y_i - \bar{y}\right)^2}\right)} \tag{6}$$

III. Results and Discussion

We researched the implementation of SimoRA LoRA utilizing three methods: analyzing the results of the SimoRA LoRA website dashboard, implementing the LoRA communication network, and analyzing the results of an electronic sensor test for seven soil fertility metrics.

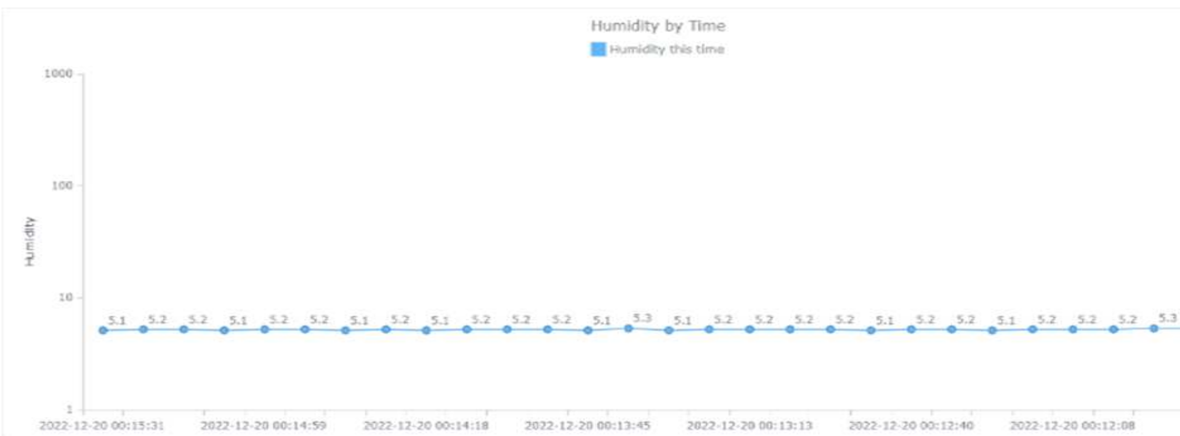

Fig. 4 Example of graphical display of temperature result of electronic sensor

A. *Analysis of SimoRA LoRA Implementation Results*

The website https://simoralora.com provides access to the final display of the soil fertility monitoring system implementation using LoRA technology. There is a login option for those who have a username and password. In this web interface design, all parameters can be displayed graphically and tabularly in real-time. This website allows the monitoring of three sensor nodes over the LoRA communication network. Each of these electronic sensors can measure soil pH, soil moisture, and soil NPK elements, as well as soil temperature. The following Fig. 4 is an example of a graphical display.

The display of the electronic sensor's soil humidity test in Fig.4 shows that the measurement results are not continuous or conform to the pattern of soil moisture detected during the time sample. This indicates that the sensor can produce data that are not static but can change dynamically in response to the detected soil moisture at that time. A dynamic graph depicting the display of NPK element readings utilizing electronic sensors is displayed in Fig.5. The values of these three elements vary over the sampling interval.

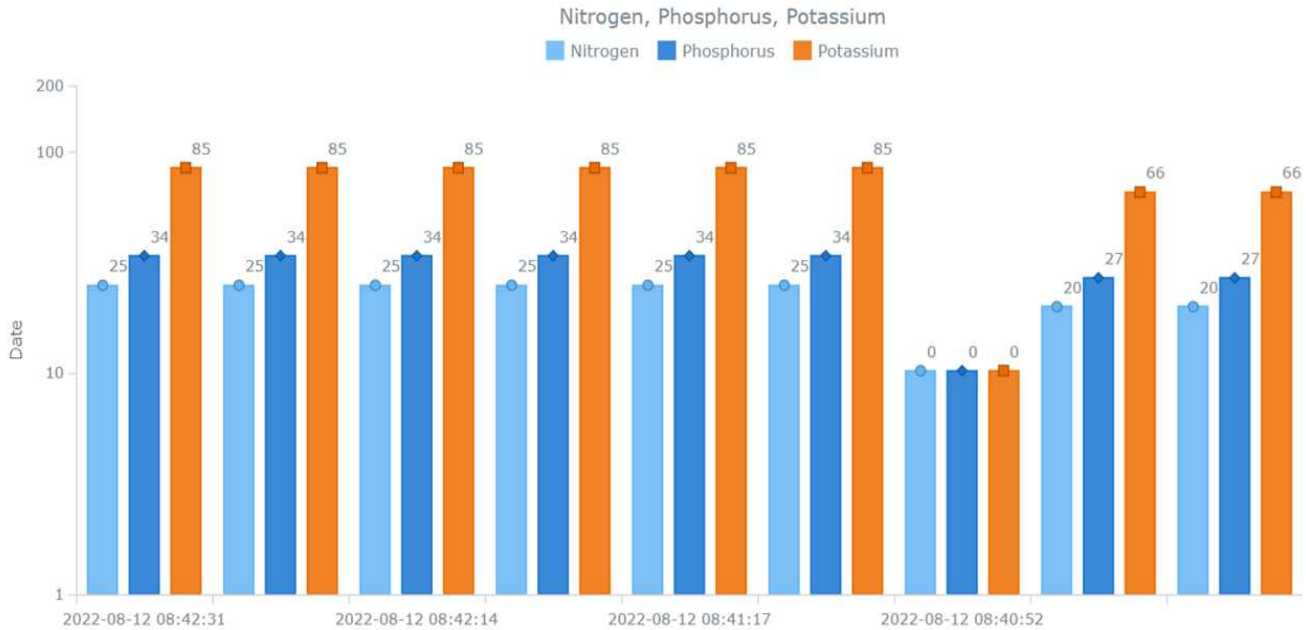

Fig. 5 Example of a graphical display of NPK results of an electronic sensor

B. *LoRA Network Design and Planning Analysis*

Using the Longley- Rice Irregular Terrain propagation model, we measured the actual quality of the received signal strength indicator (RSSI) signal at 30 places in Banyumas Regency under the LoRA network design model. Taking a sample of sites where LoRA nodes would subsequently be deployed in the form of SimoRA LoRA sensors allowed for the selection of 30 locations. These places are dispersed and have distinct regional topographies. The Longley–Rice Irregular Terrain propagation communication channel model provides signal quality information across the whole Banyumas district, as depicted in Fig. 6, with very good, good, and poor signal quality. If the signal quality is displayed on the map, the results of the RSSI simulation results for the coverage of LoRA planning in Banyumas Regency can be seen in Fig. 7.

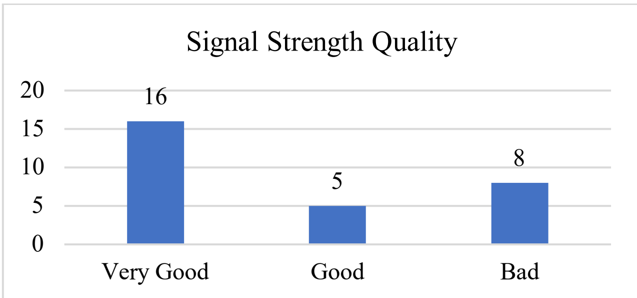

Fig. 6 RSSI classification results of LoRA planning coverage in the Banyumas district

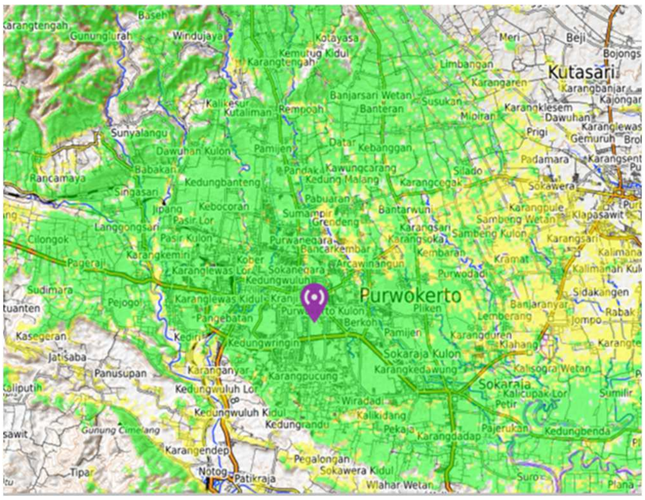

Fig. 7 RSSI simulation results of LoRA planning coverage in the Banyumas district

C. Analysis of the Results of Electronic Sensor Tests

1) Standard Deviation Results

Fig. 8 shows the standard deviation values from the three sensors after measuring the soil natrium values from the 19 samples. These data show that sensor measurements are the same when reading the same object. This proves that the soil sensors are stable in reading soil natrium values. A different sample may have different soil natrium values, but a different sensor provides the same value for reading soil natrium values in the same samples. This means that sensors provide high stability when reading natrium values.

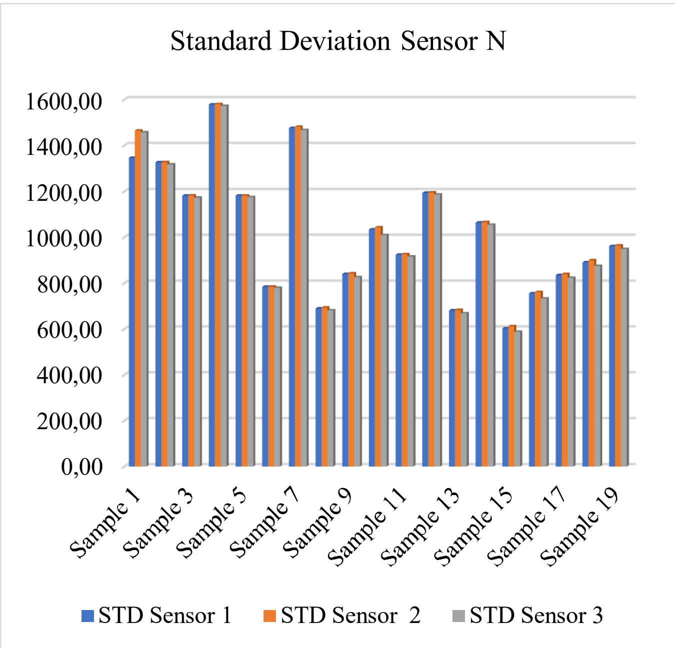

Fig. 8 Standard deviation values of nitrogen from the three sensors

The standard deviation values of the three sensors after measuring the soil phosphate values from the 19 samples are shown in Fig. 9. The data demonstrate that the sensor readings were taken from the same sample object. This demonstrates the soil sensors' accuracy in measuring the soil phosphate concentration. Soil phosphate levels can vary from sample to sample, but the results are always the same when measured with a different sensor. This indicates that sensor phosphate readings are quite stable.

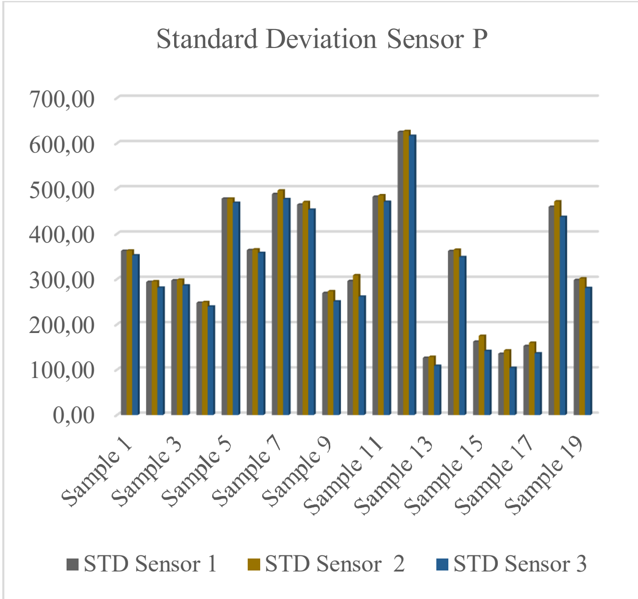

Fig. 9 Standard deviation values of phosphor from the three sensors

The standard deviation values from the three sensors after measuring the soil potassium content from the 19 samples are displayed in Fig. 9. Based on these findings, it may be deduced that the sensor readings were taken using the same sample object. This demonstrates that the soil sensors are stable in measuring the soil's potassium content. There is a possibility that the potassium levels in various samples will vary, but a different sensor will always provide the same result when reading the potassium levels in the same samples. This indicates that the sensors have a good level of stability while reading the Kalium values, which can be seen in Fig. 10.

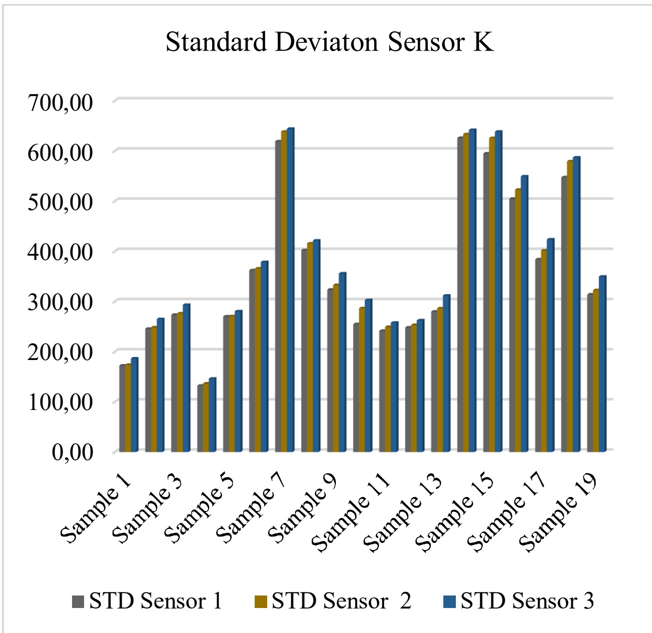

Fig. 10 Standard deviation values of electric conductivity from the three sensors

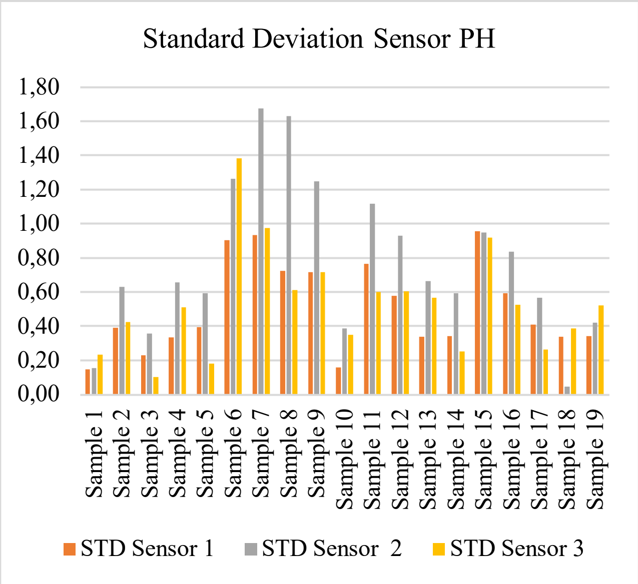

Fig. 11 Standard deviation values of pH from the three sensors

Fig.12 displays the standard deviation values obtained from the three sensors in determining the pH value of the 19 soil samples. According to these findings, every sensor produces a unique output value. It is possible to obtain a different standard deviation value from each sensor when reading different samples. The parameter that had the most accurate readings for its standard deviation was the one that measured the soil's pH value. The other six parameters had significantly larger standard deviations. This standard deviation was calculated by comparing the results of the measurements taken by the electronic sensors with the results of the soil lab measurements taken using the same soil sample. The comparison value was used to calculate the standard deviation.

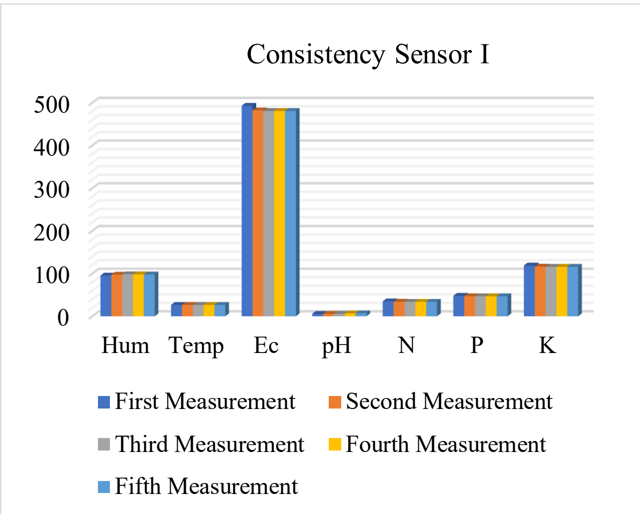

Fig. 12 Consistency measurement results from Sensor 1

2) Consistency Test

The values of Sensor 1's consistency are displayed in Fig. 13 and Table 1. In this study, Sensor 1 is utilized to measure each parameter at a certain point in time. In this investigation, four separate measurements of each parameter have already been carried out. This test demonstrates that these statistics show that Sensor 1 has high consistency. The values obtained are identical when measuring each parameter using the same sample at different times.

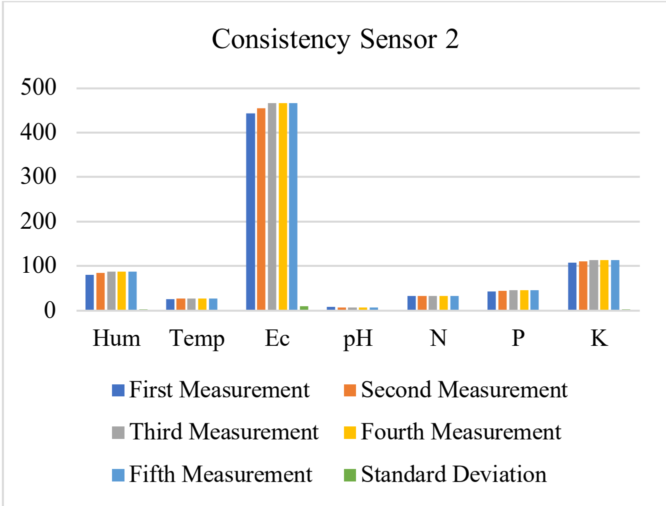

Fig. 13 Consistency measurement results from Sensor 2

TABLE I
CONSISTENCY RESULTS FROM SENSOR 1

	Hum	Temp	Ec	pH	N	P	K
First Measurement	95.5	26.6	493	5.7	35	48	119
Second Measurement	97.53	26.64	482.2	5.55	34.1	47.1	116.3
Third Measurement	98.52	26.66	481	6.05	34	47	116
Fourth Measurement	98.3	26.63	481	6.51	34	47	116
Fifth Measurement	98.1	26.56	481	6.9	34	47	116
Standard Deviation	1.22	0.04	5.26	0.56	0.44	0.44	1.31

The values of Sensor 2's consistency are shown in Fig.14 and Table 2. To measure each parameter at a specific moment, this research uses Sensor 2. In this investigation, four separate measurements of each parameter have already been carried out. This test demonstrates that Sensor 2 has high consistency, as seen in these statistics.

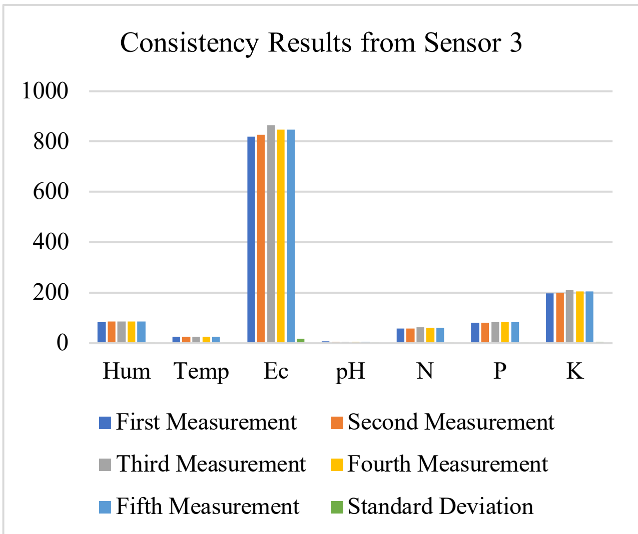

Fig. 14 Consistency measurement results from Sensor 3

TABLE II
CONSISTENCY RESULTS FROM SENSOR 2

	Hum	Temp	Ec	pH	N	P	K
First Measurement	80.76	26.16	443	7.99	32	43	107
Second Measurement	85.15	26.27	454	6.53	32.5	44	110
Third Measurement	86.92	26.35	466	6.86	33	45	113
Fourth Measurement	87.1	26.5	466	7.2	33	45	113
Fifth Measurement	86.98	26.75	466	7.4	33	45	113
Standard Deviation	2.71	0.23	10.34	0.55	0.45	0.89	2.68

The sensor 3's consistency values are shown in Fig.15 and Table 3. Throughout this study, Sensor 3 has been used to measure each variable precisely over a predetermined period. Each parameter has already been measured four times for this study. Sensor 3 is reliable in this test, according to the results. When measuring the same sample at different periods, the values for each parameter are consistent.

TABLE III
DATA MEASUREMENT RESULTS AND LABORATORY RESULTS WITH STANDARD DEVIATION

	Sensor 1	Sensor 2	Sensor 3	Lab Result	STD Sensor 1	STD Sensor 2	STD Sensor 3
Water Content (%)	80.725	69.8	74.42	46.78	24.00	16.28	19.54
Conductivity (μS/cm)	324	614.4	317	4.95	225.60	430.95	220.65
N (PPM)	23	43.55	22	1734.53	1210.23	1195.70	1210.94
pH	4.41	6.02	7.9	7.29	2.04	0.90	0.43
K (PPM)	78	148.65	76	917.95	593.93	543.98	595.35
P (PPM)	31	59.6	30	203.19	121.76	101.53	122.46

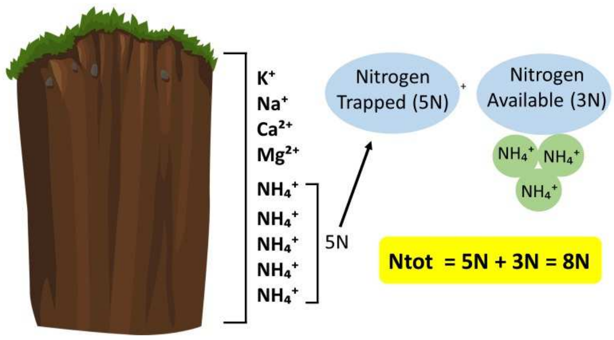

Fig. 15 Illustration of nitrogen trapped in the sensor test results and nitrogen available in the laboratory test results

3) *Correlation Test between Sensors and Lab Results*

Each sensor's correlation tests are displayed in Table 4. This finding is consistent with the sensors' high correlations, as the correlation values indicate. The correlation values in this study were gathered using data from three sensors. This information suggests that while all sensors correlate highly with one another, they do not correlate well with laboratory results. This may occur because laboratory measurements and sensor readings employ different methodologies. Measurements obtained using various approaches tend to be uncorrelated with one another are listed in Table 4. This strengthens our finding that measuring N, P, and K using the electric approach is different from soil laboratory tests. Sensors can be used with different standards and still can be used to measure N, P, and K parameters without comparing them with laboratory tests.

The outputs of the standard deviation in Table 4 parameter analysis between sensor measurement results and the soil laboratory test results show that sensor measurements and laboratory tests have a very high standard deviation for all components except pH. Furthermore, the correlation test results show no correlation between sensor values and the soil laboratory test results. This is because the methods used in electronic sensors to quantify NPK elements differ from those used in soil laboratories. The electronic sensors measured trapped nutrients from the soil, whereas the soil laboratory measured available and total nutrients. Analyzing nitrogen, Fig.15 shows that plants cannot directly absorb soil-bound nutrients. When nutrients are available in the soil, the value of these nutrients can be determined using the soil laboratory test results. The total nitrogen value can be evaluated using soil laboratory testing if the combined value of nitrogen trapped and available nitrogen is known.

TABLE IV
CORRELATION TEST RESULTS BETWEEN ALL SENSORS

Cross-correlation between Sensor 1 and Sensor 2	Cross-correlation between Sensor 1 and Sensor 3	Cross-Correlation Between Sensor 1 and the Lab	Cross-correlation between Sensor 2 and Sensor 3	Cross-correlation between Sensor 2 and the Lab	Cross-correlation between Sensor 1 and the Lab
0.9890	0.99976	-0.3346	0.99132	-0.282	-0.336

IV. CONCLUSION

We have implemented a soil fertility monitoring system in Banyumas Regency utilizing LoRA technology, and the results are accessible via the SimoRA LoRA application. This research has contributed to an examination of the performance of electronic sensors in terms of sensor accuracy, sensor consistency, and sensor correlation with lab test results from the perspective of the LoRA communication network's planning. We have developed a LoRA communication network planning using the Longley–Rice Irregular Terrain Model channel, resulting in 16 regions with very good RSSI conditions, five with good RSSI conditions, and only eight with bad RSSI circumstances.

Three sensors are utilized, and the results are compared to those of a soil lab test. The standard deviation between sensor measurement and soil laboratory test results is the most important sensor accuracy parameter. The standard deviation of the sensor with lab test results is extremely high, whereas the standard deviation for Sensors 1 through 3 is not significantly different. Except for the pH value parameter, the standard deviation between sensor measurements and soil lab test results is very different. This implies discrepancies between the methodologies used to quantify soil fertility parameters, particularly NPK, from electronic sensors and soil lab tests. In terms of the consistency of the electronic sensors deployed, the outputs of the five trials indicate that the values generated by the sensors are always the same. This clearly shows that the sensor has a high level of consistency, as its reading rate is identical to past results.

The final element of the results is the correlation value between sensors, the correlation test between sensors, and lab test results for soil. In the correlation test, each sensor's reading of the same soil fertility parameters gives a correlation coefficient approaching 1, implying that the sensor measurement results are highly correlated. While the correlation test between the sensor readings and the soil lab test has a very low correlation coefficient, this indicates that the method employed by the electronic sensor is unrelated to the method adopted by the soil lab.

NOMENCLATURE

f	signal frequency	Hz
d	distance from the transmitter to the receiver	meters
PL	path loss	dB
χ_σ	random variable Gaussian	dB
Pdf	probability density function	
r	the amplitude of the envelope signal	A
σ	the standard deviation	
K	the coefficient reflection of the channel	

ACKNOWLEDGMENT

We thank the Telkom Purwokerto Institute of Technology, Indonesia Telecommunication and Digital Research Institute, and the Department of Agriculture of Banyumas Regency for conducting this research.

REFERENCES

[1] H. D. Foth and B. G. Ellis, Soil Fertility. CRC Press, 2018. doi: 10.1201/9780203739341.

[2] S. G. Surya, S. Yuvaraja, E. Varrla, M. S. Baghini, V. S. Palaparthy, and K. N. Salama, "An in-field integrated capacitive sensor for rapid detection and quantification of soil moisture," *Sensors Actuators, B Chem.*, vol. 321, no. June, p. 128542, 2020, doi:10.1016/j.snb.2020.128542.

[3] R. S. Freeland, "Review of soil moisture sensing using soil electrical conductivity," *Trans. Am. Soc. Agric. Eng.*, vol. 32, no. 6, pp. 2190–2194, 1989, doi: 10.13031/2013.31283.

[4] J. Knappett and R. F. Craig, Craig's Soil Mechanics. CRC Press, 2019. doi: 10.1201/9781351052740.

[5] K. Terzaghi, "Theoretical Soil Mechanics," Jan. 1943, doi: 10.1002/9780470172766.

[6] S. U. Susha Lekshmi, D. N. Singh, and M. Shojaei Baghini, "A critical review of soil moisture measurement," *Meas. J. Int. Meas. Confed.*, vol. 54, pp. 92–105, 2014, doi: 10.1016/j.measurement.2014.04.007.

[7] B. Lowery, W. J. Hickey, M. A. C. Arshad, and R. Lal, "Soil Water Parameters and Soil Quality," *Methods Assess. Soil Qual.*, pp. 143–155, Oct. 2015, doi: 10.2136/SSSASPECPUB49.C8.

[8] N. Sarkar, B. Chandra, K. Viswavidyalaya, and T. Majhi, "Study on soil moisture variations in responding to Tensiometer and soil moisture meter with respect to gravimetric method," *Int. J. Chem. Stud.*, vol. 7, no. 4, pp. 3179–3188, 2019, doi: 10.13140/RG.2.2.29810.86723.

[9] M. A. Sulthoni and M. A. Rizqulloh, "A Low Cost Microcontroller-based Time Domain Reflectometer for Soil Moisture Measurement," *Proc. Int. Conf. Electr. Eng. Informatics*, vol. 2019-July, no. July, pp. 197–200, 2019, doi: 10.1109/ICEEI47359.2019.8988875.

[10] T. Thamrin, I. S. Marpaung, and T. Arief, *Penggunaan Perangkat Uji Tanah Sawah (PUTS)*. Palembang: Balai Pengkajian Teknologi Pertanian Sumater Selatan, 2011.

[11] G. T. Patterson and M. R. Carter, *Soil Sampling and Handling*, 2nd ed., vol. 44. CRC Press Taylor & Francis Group, 2006.

[12] S. R. Khan, B. Sharma, P. A. Chawla, and R. Bhatia, "Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES): a Powerful Analytical Technique for Elemental Analysis," *Food Anal. Methods 2021 153*, vol. 15, no. 3, pp. 666–688, Nov. 2021, doi: 10.1007/S12161-021-02148-4.

[13] D. Perdana, L. Renaldi, and I. Alinursafa, "Performance Analysis of Soil Moisture Monitoring based on Internet of Things with LoRA Communications," *J. Southwest Jiaotong Univ.*, vol. 55, no. 5, pp. 55–64, 2020, doi: 10.35741/issn.0258-2724.55.5.31.

[14] T. F. Prasetyo, E. A. Frastya, and Enceng Enda S, "Sistem Pendeteksi Kesuburan Tanah Pada Desa Cihaur Kelompok Tani Bina Mandiri," in *Seminar Nasional SINERGI*, 2017, pp. 191–198.

[15] H. Marcos and H. Muzaki, "Monitoring Suhu Udara Dan Kelembaban Tanah Pada Budidaya Tanaman Pepaya," *J. Teknol. dan Sist. Tertanam*, no. 127, 2022.

[16] N. Effendi, W. Ramadhani, and F. Farida, "Perancangan Sistem Penyiraman Tanaman Otomatis Menggunakan Sensor Kelembapan Tanah Berbasis IoT," *J. CoSciTech (Computer Sci. Inf. Technol.*, vol. 3, no. 2, pp. 91–98, 2022, doi: 10.37859/coscitech.v3i2.3923.

[17] M. A. Martínez-Gimeno *et al.*, "Mandarin irrigation scheduling by means of frequency domain reflectometry soil moisture monitoring," *Agric. Water Manag.*, vol. 235, no. July 2019, p. 106151, 2020, doi: 10.1016/j.agwat.2020.106151.

[18] J. Haxhibeqiri, E. De Poorter, I. Moerman, and J. Hoebeke, "A survey of LoRaWAN for IoT: From technology to application," *Sensors (Switzerland)*, vol. 18, no. 11, 2018, doi: 10.3390/s18113995.

[19] S. Gutierrez, I. Martinez, J. Varona, M. Cardona, and R. Espinosa, "Smart Mobile LoRa Agriculture System based on Internet of Things," 2019 IEEE 39th Central America and Panama Convention (CONCAPAN XXXIX), Nov. 2019, doi:10.1109/concapanxxxix47272.2019.8977109.

[20] F. Deng, P. Zuo, K. Wen, and X. Wu, "Novel soil environment monitoring system based on RFID sensor and LoRa," *Comput. Electron. Agric.*, vol. 169, no. December 2019, p. 105169, 2020, doi:10.1016/j.compag.2019.105169.

[21] A. W. Jannah, R. Primananda, and A. Bhawiyuga, "Implementasi Protokol LoRa pada Akuisisi Data Sensor Perikanan menggunakan Drone Agent sebagai Node Perantara," *J. Pengemb. Teknol. Inf. dan Ilmu Komput.*, vol. 4, no. 1, pp. 390–396, 2020.

[22] A. Siddique, B. Prabhu, A. Chaskar, and R. Pathak, "a Review on Intelligent Agriculture Service Platform With Lora Based Wireless Sensor Network," *Int. Res. J. Eng. Technol.*, vol. 06, no. 02, pp. 2539–2542, 2019.

[23] M. Ji, J. Yoon, J. Choo, M. Jang, and A. Smith, "LoRa-based Visual Monitoring Scheme for Agriculture IoT," *SAS 2019 - 2019 IEEE Sensors Appl. Symp. Conf. Proc.*, pp. 1–6, 2019, doi:10.1109/SAS.2019.8706100.

[24] L. Kolobe, B. Sigweni, and C. K. Lebekwe, "Systematic literature survey: Applications of LoRa communication," *Int. J. Electr. Comput. Eng.*, vol. 10, no. 3, pp. 3176–3183, 2020, doi:10.11591/ijece.v10i3.pp3176-3183.

[25] J. Arshad *et al.*, "Implementation of a LoRaWAN Based Smart Agriculture Decision Support System for Optimum Crop Yield," *Sustain.*, vol. 14, no. 2, pp. 1–20, 2022, doi: 10.3390/su14020827.

[26] R. Gilson and M. Grudsky, "LoRaWAN Capacity trial in Dense urban environment," 2017.

[27] C. Pham, A. Bounceur, L. Clavier, U. Noreen, and M. Ehsan, *Radio Channel Access Challenges in LoRa Low Power Wide Area Networks*. INC, 2020.

[28] J. M. Marais, R. Malekian, and A. M. Abu-Mahfouz, "LoRa and LoRaWAN testbeds: A review," *2017 IEEE AFRICON Sci. Technol.*

Innov. Africa, AFRICON 2017, pp. 1496–1501, 2017, doi:10.1109/AFRCON.2017.8095703.

[29] M. H. Habaebi, I. J. Chowdhury, M. R. Islam, and N. A. B. Zainal, "Effects of shadowing on LoRa LPWAN radio links," *Int. J. Electr. Comput. Eng.*, vol. 7, no. 6, pp. 2970–2976, 2017, doi:10.11591/ijece.v7i6.pp2970-2976.

[30] G. a Hufford, a G. Longley, and W. a Kissick, "A Guide to the Use of the ITS Irregular Terrain Model in the Area Prediction Mode," 1982.

[31] A. Gutiérrez-Gómez *et al.*, "A propagation study of LoRA P2P links for IoT applications: The case of near-surface measurements over semitropical rivers," *Sensors*, vol. 21, no. 20, 2021, doi:10.3390/s21206872.