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Low-Cost LoRaWAN Solution for Groundwater Monitoring in Peatlands

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Abstract

Some efforts made in restoring peatlands include moisture restoration, replanting, hydrological restoration, monitoring, and evaluation using technology to obtain periodic condition data. The implementation of the Water Level Logger (WLL) for monitoring groundwater levels in peatlands still faces issues because the sensor installation points are not served by cellular communication networks for data transmission. This research aims to implement a Low Power Wide Area Network (LPWAN) as a low-cost infrastructure used in applications for monitoring water levels in peatland. The method in this research is an approach to develop LoRaWAN gateway devices and servers using ChirpStack, equipped up to the application layer as supporting infrastructure for self-hosted groundwater level monitoring tools integrated with a time-series database and displaying measurement data on a dashboard periodically. Based on the tests, the average measurement of the Received Signal Strength Indicator (RSSI) obtained at the farthest distance of 3 km was -116 dBm, where the RSSI value also decreased with each additional distance, and the Line-of-Sight (LOS) condition significantly affected the RSSI value. This research shows that a real-time peat groundwater monitoring system has been successfully built at a low cost using self-hosted LoRaWAN gateways and servers, while maintaining reliability.

Keywords: LoRaWAN, Peatland, Groundwater, RSSI

1. INTRODUCTION

Indonesian peatlands and peat swamp forests cover an area of 21 million hectares, representing about 36% of the world's tropical peatlands. However, most of Indonesia's tropical peatlands have been degraded since the 1980s through deforestation and drainage, primarily for forestry and agricultural purposes[1]. The large-scale construction of drainage canals in peatland ecosystems will excessively affect the drying process of the surrounding peatland. The decrease in the water table on peatland will result in the oxidation process or an increase in oxygen content, the occurrence of subsidence, and the potential risk of land fires.

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Currently, Badan Restorasi Gambut dan Mangrove (BRGM) has a program to address this issue, namely the rewetting, revegetation, and revitalization of livelihoods program for peatland restoration in Indonesia. One of the efforts in peatland rewetting techniques is the construction of canal blocks due to excessive groundwater table decline caused by drainage channels, which can anticipate peatland fires and serve as a strategy for peatland management through peatland restoration.

Additionally, IoT technology is also being implemented by installing sensors to measure the groundwater level in peatlands. A wireless communication network infrastructure is needed to support IoT-based sensors in peatland areas far from settlements, where communication network access is unavailable. Wireless technology can provide extensive coverage, but it has high power consumption.
The development of Low Power Wide Area Network (LPWAN) technology presents itself as the right solution due to its low power consumption, ability to transmit data over long distances, and affordable cost[2]. LoRaWAN is an LPWAN technology widely adopted by the industrial and academic sectors today because it can operate on unlicensed frequencies. Speed settings, power consumption, and throughput can be adjusted for IoT applications and are considered one of the solutions to various IoT implementation issues in Indonesia[3].

The primary method of communication between each LoRa active node will be point-to-point. Although the service area is constrained, LoRaWAN facilitates connection between LoRa nodes and distant end nodes via LoRa gateways, allowing the network to provide long-distance communications on par with those of a WAN network[4]. LoRaWAN use LoRa modulation to establish LPWANs in a star architecture that includes end nodes, gateways, network servers, and application servers. It contributes a minimum of 13 bytes to each payload broadcast from an end node to the gateways, while LoRa's bit rate, range, and airtime are contingent upon the spreading factor[5]. In the case of LoRaWan technology, the gateway uses the LoRaWAN protocol, which is responsible for managing the communication between the end devices and the LoRa gateway, as well as providing security, data encryption, and authentication[6]. LoRaWAN's network server can be run in two ways: cloud-hosted and self-hosted. Cloud-hosted services include The Thing Stack, Helium, and AWS IoT Core. Meanwhile, self-hosted refers to open-source applications that we can use, such as Chirpstack, TTN, or open-source servers[7].

Water Level Logger (WLL) is a critical element in the monitoring of water levels in peatland areas by the National Peatland and Mangrove Restoration Agency (BRGM). In contrast, this instrument encounters a variety of limitation, such as sensor locations that are not accessible via cellular communication networks and

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substantial operational costs. Consequently, the development of a supporting infrastructure for groundwater level monitoring systems that utilize remote communication is necessary.

This research develops LoRaWAN gateway and server devices that will be used as supporting infrastructure for the groundwater level monitoring system in peat conservation areas located in Ketapang Regency. This research designs a LoRaWAN Gateway device for outdoor area coverage on the Indonesian frequency standard AS923[8]. The Gateway and LoRaWAN Server devices are designed to operate in conjunction within a self-hosted SBC Raspberry-Pi device. This feature integration enables the complete inclusion of features at the application layer, including the integration of services such as MQTT Broker, Time-series DB, and other supporting IoT applications.

2. METHODS

Gateway and sensor devices are built using free and open-source software. In addition, hardware components such as Single Board Computers (SBC), LoRaWAN modules, expansion boards, antennas, sensors, and microcontrollers were obtained through online markets.

2.1. LoRaWAN Gateway

The Gateway device, a LoRaWAN network server, is designed and built with the following main components.

1) Raspberry-Pi

The Raspberry Pi used as a gateway and server in this research is of the type 4B, single-board computer with a quad-core ARM Cortex-A72 processor, and 4GB of RAM. It's widely used in educational projects, prototyping, IoT applications, media centers, and small server setups. It supports multiple USB 3.0 ports, dual 4K HDMI outputs, gigabit Ethernet, and Wi-Fi, making it a versatile platform for a variety of tasks. The Raspberry Pi, a compact and affordable single-board computer, has emerged as a pivotal tool in various domains, including education, research, and industrial applications[9]. The SBC Raspberry Pi was chosen as the gateway and server device because this platform is very flexible, affordable, and has sufficient computing power to run several services and applications needed in system development. In addition, it is also highly compatible with many LoRaWAN concentrator modules.

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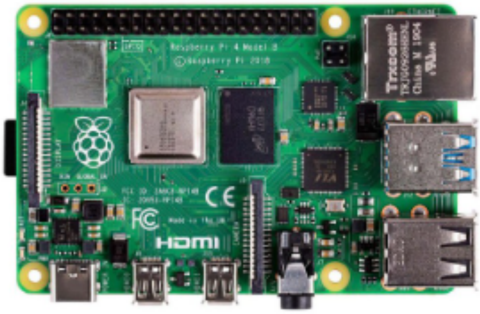

Figure 1. Raspberry-Pi 4B Board

2) LoRaWAN Concentrator Module

The LoRaWAN concentrator module used is the RAK2287 type developed by RAKwireless, and it is used to enable low-power wide-area network (LPWAN) communication for Internet of Things applications. (IoT). The module uses the Semtech SX1301 chipset, a powerful LoRa gateway chip that supports multi-channel and multi-data rate operation, allowing it to handle a high volume of LoRa traffic. RAK2287 is a LoRaWAN concentrator module that is frequently employed in the construction of LoRaWAN gateways. This decision is made on the basis of a variety of technical benefits and functionalities, including low power consumption, compatibility with LoRaWAN Stacks such as Chirpstack and TTN, flexible frequency support in accordance with regulations, and compatibility with other LoRaWAN modules.

Figure 2. RAK2287 LoRaWAN Gateway Hat

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3) Omni Antenna

An Omni LoRaWAN Antenna 10dBi is a type of antenna designed for use in LoRaWAN (Long Range Wide Area Network) communication systems. It is providing 360-degree coverage with frequency range 860-930Mhz.

Figure 3. 10dBi Omni Antenna

2.2. Sensor Node

Concurrently, the sensor apparatus designed to measure groundwater levels has the following primary components.

1) Heltec Wireless Stick Lite

The microcontroller used in the sensor node is the Heltec Wireless Stick Lite, which is a compact development board designed for wireless IoT applications, specifically for low-power long-range communication using technologies such as LoRa (Long Range) and Wi-Fi. This board supports the LoRaWAN communication protocol at operating frequencies of 860-930 MHz.

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Figure 4. Microcontroller Unit (MCU)

2) Ultrasonic Range Sensor

The distance sensor used to measure the groundwater level is an ultrasonic sensor with UART connection. This sensor uses ultrasonic sound waves to measure the distance between the sensor and the object, with a range of up to 8 meters.

Figure 5. Ultrasonic Sensor

2.3. System Design

This self-hosted gateway and LoRaWAN server are constructed utilizing ChirpStack, an open-source LoRaWAN network server that facilitates communication between LoRaWAN devices and applications. The system comprises a comprehensive array of components, including a Gateway Bridge, Gateway Concentrator, Network Server, and Application Server, facilitating the establishment and management of a LoRaWAN network. Figure 6 summarizes its principal components:

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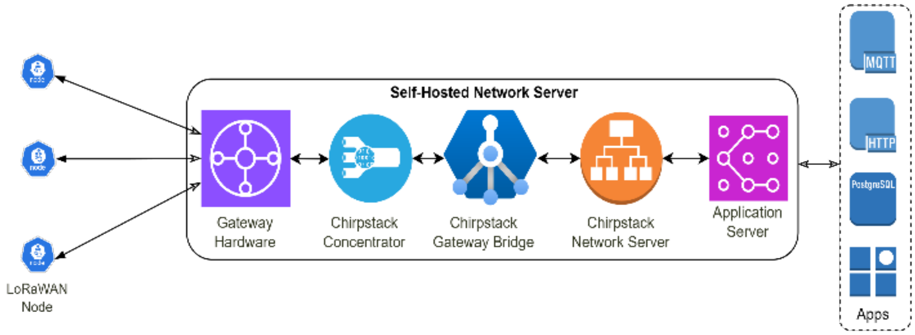

Figure 6. System Architecture

1) Gateway Concentrator: allows gateway hardware and nodes to communicate. It improves LoRaWAN data reception and routing by transferring data to gateways.
2) Gateway Bridge: functions as an intermediary, enabling the network server to communicate seamlessly with the gateway hardware. It guarantees the proper management and transmission of data to ensure the efficient operation of a network.
3) Network Server: oversees the complete network, encompassing device activation, data routing, and communication with the nodes. It is essential for sustaining transparent, bidirectional communication within the LoRaWAN network.
4) Application Server: links the network server to external applications and services. The LoRaWAN network and external applications interact seamlessly because it manages storage, data processing, and database and dashboard integration.

The design of the gateway hardware in this research can be seen in the block diagram of components in Figure 7.

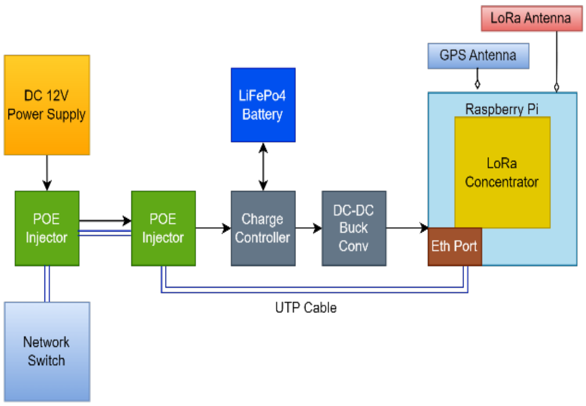

Figure 7. Gateway Component Block Diagram

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Figure 8 shows the assembly results of the Gateway hardware designed to support the integration between the gateway and server in a single board computer.

Figure 8. LoRaWAN Gateway

The design of the Sensor-Node hardware in this research can be seen in the block diagram of components in Figure 9.

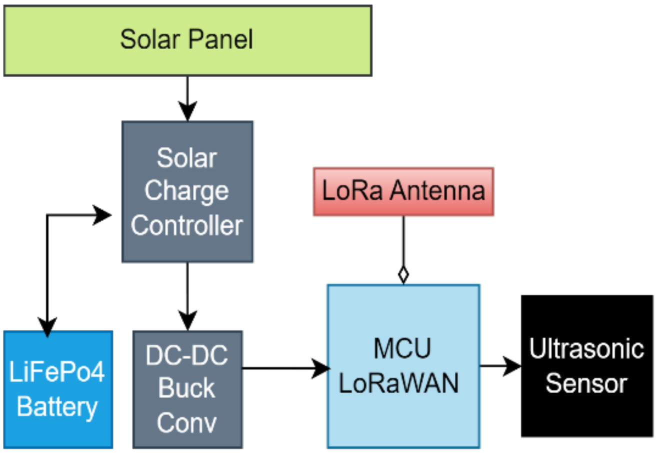

Figure 9. Sensor-Node Block Diagram

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Figureure 10 shows the assembly results of the Sensor-Node hardware, specifically designed to operate by sending groundwater level data using a solar energy source equipped with LifePo4 batteries.

Figure 10. Solar powered Sensor-Node

3. RESULTS AND DISCUSSION

3.1 LoRaWAN Server Development

In this research, there are several steps in creating a gateway system with ChirpStack, starting with the installation and updating of operating system packages on the raspberry-pi device. This is followed by the installation of the necessary dependency packages for ChirpStack and the installation of the three main ChirpStack components: Network Server, Application Server, and Gateway Bridge. The next step is to perform the necessary conFigureurations such as the LoRaWAN Frequency Plan, Network Server settings, and database connection. This LoRaWAN server is equipped with a web interface, which can be accessed by default on port 8080. Figure11 shows the admin dashboard on the application server.

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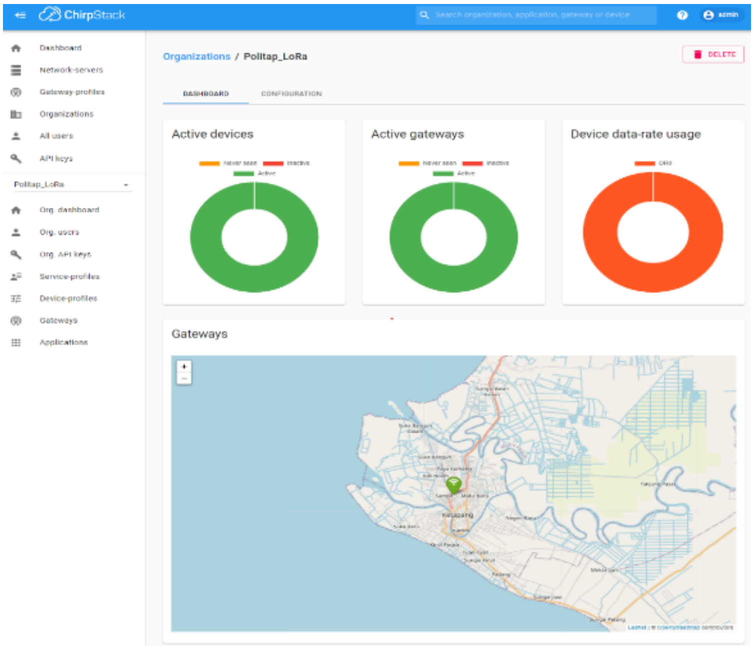

Figure 11. Application Server Dashboard

Before being able to implement LoRaWAN devices and manage applications through ChirpStack, it is necessary to add gateway devices and conFigureure the parameters on the gateway profile that will be added. Figure12 shows the view of the addition of the first gateway to be operated, and Figure 13 is the creation of the service profile to deploy the LoRaWAN application.

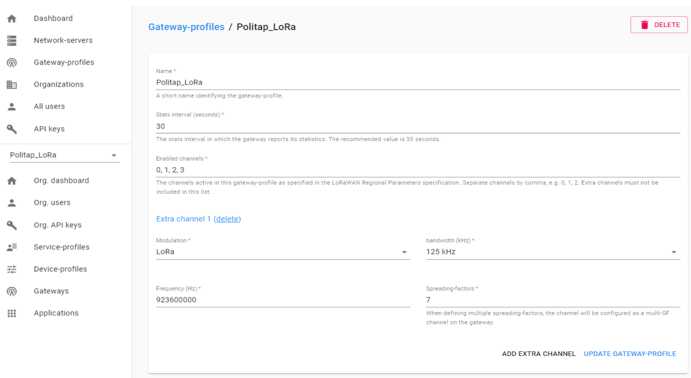

Figure 12. Create gateway profile

The addition of additional channels can be done at this stage, in addition to the selection of frequency, bandwidth, and spreading factor (SF) which must be adjusted according to the desired regulations and reliability.

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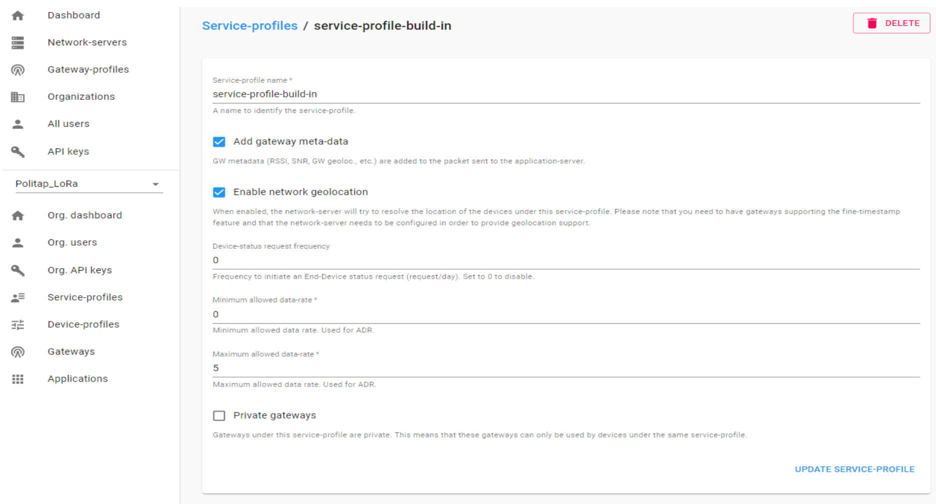

Figure 13. Adding service profile

Adding profiles and setting device parameters need to be done before creating the application. Figure 14 is the device profile created according to the specifications of the Sensor-Node device, and Figure 15 shows that the Sensor-Node device can now connect to the application by registering the DevEUI, AppEUI, and AppKey codes on the Sensor-Node device that will connect to the application created on the Network Server.

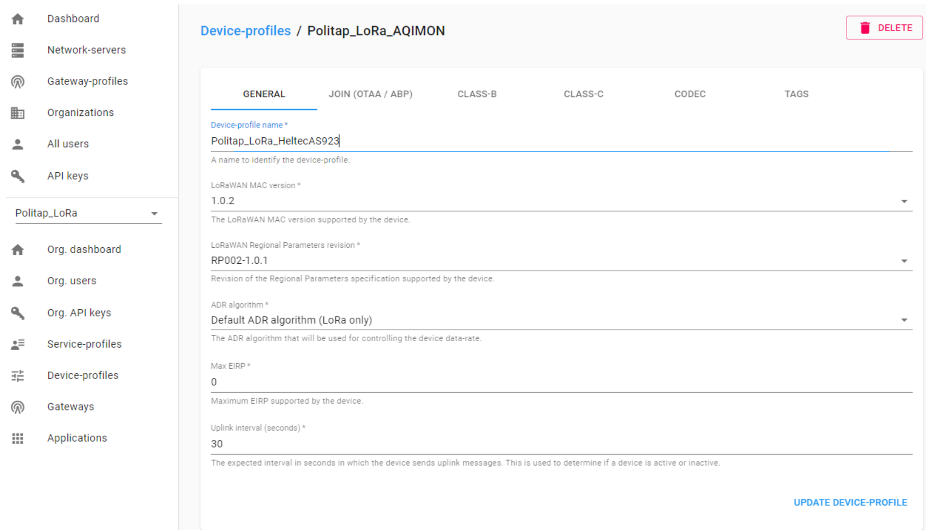

Figure 14. Create device profile

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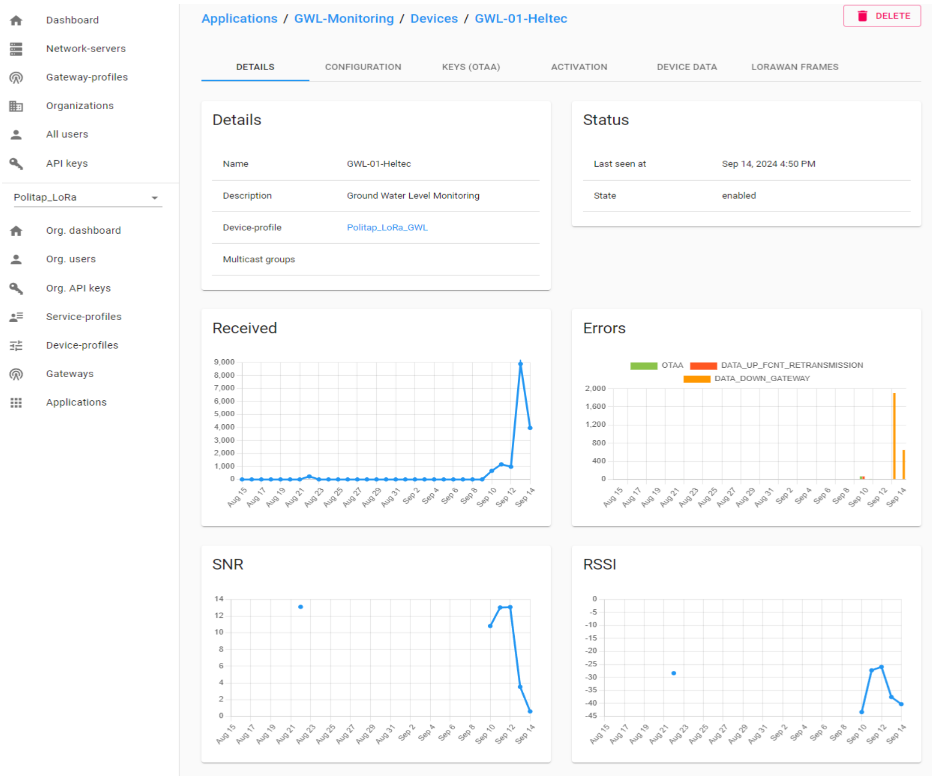

Figure 15. Application Status

The application used as a groundwater level monitoring system in this research is Grafana, an open-source platform for data visualization and monitoring that enables querying, visualization, and analysis of time series data. It is often used in conjunction with time series databases (such as Prometheus, InfluxDB, or TimescaleDB) to develop interactive and real-time dashboards for monitoring and observability purposes. To connect the decoded sensor data with the database, Node-RED needs to be used[11]. Figure 16 shows the integration of sensor data into the InfluxDb database using Node-RED.

After the data has been successfully read and integrated into the InfluxDB database, the next step is to install and conFigureure Grafana. Figure 17 shows the time-series data from the stored sensor that can be displayed on the dashboard periodically.

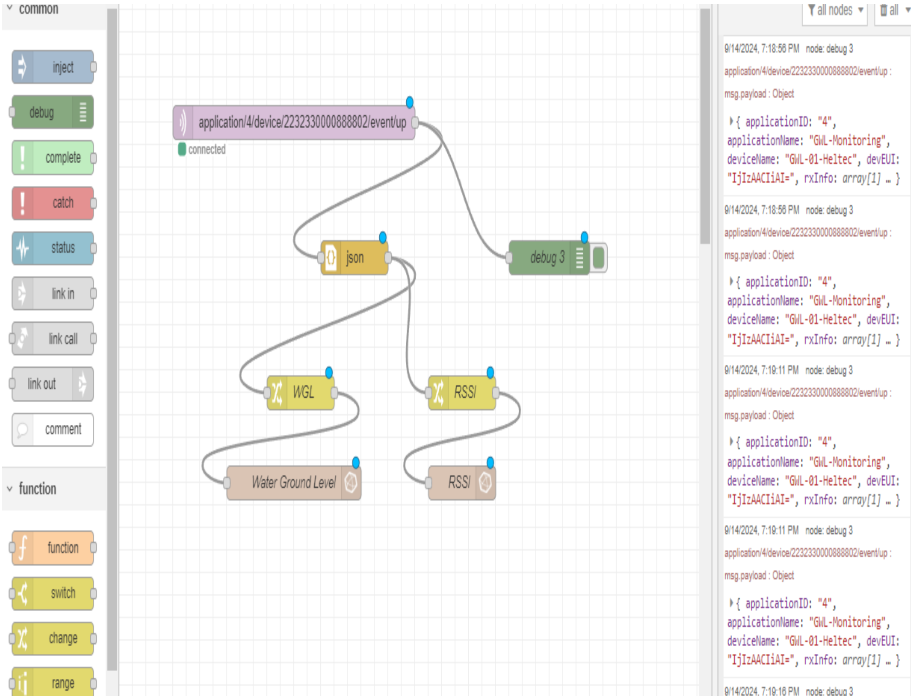

Figure 16. Integration Sensor data with Node-RED

Figure 17. Water Ground Level Monitoring Dashboard

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The displayed sensor data only includes two parameters, namely the groundwater level and the RSSI value from LoRaWAN communication. Figureures 18 show the data displayed on the dashboard in the form of charts and gauges, as well as the sensor location on the map.

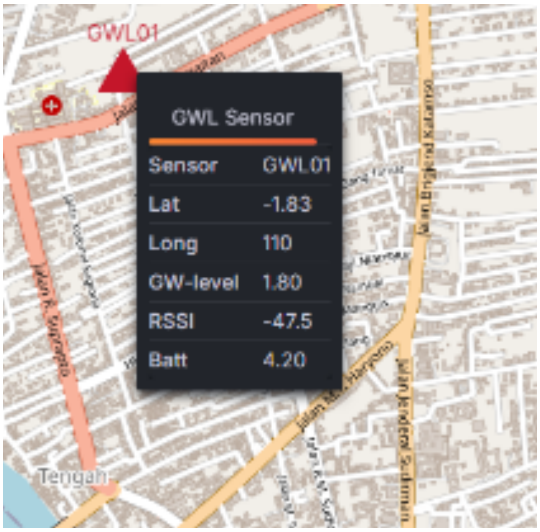

Figure 19. View Sensor data on the map

3.2 Communication Test

The Received Signal Strength Indicator (RSSI) is an essential parameter for assessing the efficacy of LoRaWAN networks. RSSI offers a quantitative assessment of the power level detected by a receiver from a sent signal, crucial for evaluating the communication quality between end devices and gateways. In the context of LoRaWAN, RSSI values can provide network operators with information about the quality of the signal and assist in the formulation of decisions to optimize the network, such as modifying the spreading factor or altering the transmission power, to improve performance. RSSI measurements were conducted 10 times for data transmission across 6 locations at varying distances in Ketapang Regency.

Tabel 1. RSSI Measurement

Distance (km)	Min	Average RSSI (dBm)	Max
0,5	-101	-89	-87
1,0	-104	-96	-95
1,6	-107	-102	-100
1,9	-109	-104	-102

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Distance (km)	Min	Average RSSI (dBm)	Max
2,5	-113	-107	-105
3,0	-116	-114	-113

According to the test results, Table 1 indicates that the RSSI values vary from -87 dBm to -116 dBm. Measurements at the minimum distance of 0.5 km produce the maximum RSSI value of -87 dBm. At the maximum test distance of 3 km, the minimum value of -116 dBm is attained. The RSSI value diminishes as the distance from the end-node to the gateway grows, as demonstrated by the average RSSI value. Nonetheless, the pace of decline is not particularly substantial. Conversely, the RSSI exhibits relative stability when analyzed over the spectrum of RSSI values at each test location. The RSSI value is affected by the Line-Of-Sight (LOS) circumstances between the gateway and the end-device; hence, the elevation of the gateway installation or the positioning of the end-device considerably impacts RSSI performance. The LoRaWAN topology, utilizing a point-to-multipoint conFigureuration, is significantly influenced by the position of the gateway installation, affecting the coverage area. Moreover, inclement weather can impact the dependability of the network connection. To mitigate this issue, it is necessary to create a mesh topology for LoRaWAN sensors and gateways in the future. Implementing a mesh architecture is anticipated to enhance coverage area, data transmission failure tolerance, and overall network resilience through improved redundancy and connection availability.

4. CONCLUSION

Inexpensive LoRaWAN gateways and servers might serve as a cost-effective solution for real-time monitoring of groundwater levels, particularly for assessing peatland conditions. The constructed LoRaWAN gateway must have its range improved by raising the device to boost connectivity, as shown by the results of the RSSI measurement tests. To enhance scalability in the extensive peatland conservation project, a superior architecture should be implemen`ted by incorporating more gateways and sensors that may redundantly interface with one another, rather than relying on the current point-to-multipoint conFigureuration. Future endeavors may encompass the incorporation of artificial intelligence for data analytics and a mesh network topology to enhance network reliability.

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