

Automated Groundwater Monitoring System with Real-time Data Collection and Analysis Using LoRa and GSM Technologies

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Abstract — Groundwater monitoring is crucial, particularly in drought-prone areas. Manual methods are time-consuming, inaccurate and weather-dependent. GSM solutions are costly and energy-intensive with limited network coverage and other currently existing works and methodologies have certain limitations. Taking these, other factors and limitations into consideration when it comes to monitoring underground water, this research presents an innovative automated system using energy-efficient LoRa technology for real-time monitoring, enhancing efficiency and reliability while reducing costs and energy consumption. The main purpose of this study is to develop and validate an innovative automated groundwater monitoring system that employs energy-efficient LoRa technology for real-time data collection and analysis, thereby overcoming the limitations of manual methods and traditional GSM solutions while ensuring enhanced reliability, scalability and cost-effectiveness. Additionally, the main contribution is the development of an innovative system used for underground water monitoring and comparison of effectiveness of LoRa based network with the GSM based network, comparing the effectiveness of this system with different network topologies when it comes to establishing such a system. Star, line and mesh network topologies were deployed to optimize data transmission and energy efficiency, packet loss and latency of these topologies were evaluated, thus enabling innovative continuous and automated groundwater monitoring. Results show the LoRa-based system significantly reduces energy consumption and operational costs compared to GSM with reliable data transmission even in areas with limited mobile

coverage. This research and validation demonstrate the feasibility and advantages of integrating LoRa technology with different topologies into groundwater monitoring systems, providing a scalable solution for sustainable water management, especially in water-scarce regions. Wireshark was used to analyze the results in terms of latency, considering the convenience of the different topologies in different scenarios. The Introduction section highlights the topicality of the topic, study purpose and reviews the current state-of-the-art with limitations of existing approaches addressed by this research. The Materials and Methods section details the design and implementation of the system, with the Results and Discussion section presenting our findings. Finally, the Conclusion section discusses the scientific contributions and value of our research and outlines potential areas for further improvement.

Keywords — Diver sensor, LoRa, NodeMCU Wi-Fi module, Raspberry Pi.

I. INTRODUCTION

In recent years, water scarcity has emerged as a critical issue impacting various regions around the world, including Uzbekistan. The country, with its arid climate and reliance on agriculture, faces significant challenges due to drought conditions and inefficient water management practices. According to sources, lack of water in central Asian countries is causing an 11 percent decrease in their GDP and according to the UN, countries in this region lose

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at least \$1.75 billion annually due to inconsistent coordination of water use [1]. Apart from that, water coming from Amudarya, one of the two main rivers in Uzbekistan, will decrease dramatically [2]. During the summer months, agricultural crops suffer considerably, exacerbated by the improper planning and execution of irrigation without an adequate understanding of groundwater levels. This situation highlights the urgent need for innovative solutions and research to optimize water usage and enhance agricultural productivity. Research indicates that within the next 20 years, the demand for water in Uzbekistan will substantially increase, while available water resources will sharply decrease, potentially amplifying the current water shortage up to five times, thus categorizing Uzbekistan as a red region in terms of water scarcity [3]. Apart from these sources, there are a lot of sources that will support how dire the situation is.

Groundwater, an essential resource for agriculture, often goes unmonitored due to the limitations of traditional methods. Accurate and timely data on groundwater conditions, such as salinity, temperature, flow speed and water level, can revolutionize water management practices which can help in terms of addressing the above-mentioned water scarcity. However, conventional approaches, including manual monitoring and GSM-based systems, are often energy-intensive, costly and limited by mobile network coverage, especially in remote areas.

Considering this, the primary objective of this research is to design, implement and rigorously evaluate an innovative automated groundwater monitoring system that leverages energy-efficient LoRa technology. By addressing the limitations associated with manual monitoring and conventional GSM approaches, this study aims to provide a robust framework for real-time data acquisition, enhanced network reliability and sustainable water resource management in water-scarce regions. Precisely, this work introduces an advanced groundwater monitoring system leveraging LoRa (Long Range) wireless technology. LoRa offers a low-power, cost-effective solution for long-range communication, making it ideal for remote monitoring applications and real-time groundwater monitoring, thus facilitating informed decision-making for irrigation management. Our system employs a diver device placed at a depth of 150 meters to measure various groundwater parameters. The data collected by the diver is processed by an Arduino, which then transmits the data via LoRa to a central Raspberry Pi. Experiments were carried out with different network topologies—star, line and mesh—to determine the most efficient configuration for data transmission. The data is further relayed to a custom server using a NodeMCU WiFi module for comprehensive analysis and monitoring. Additionally, this research provides insights into which network topologies should be used under different conditions and results of the different topologies in terms of coverage, power consumption, delay and packet loss are compared and represented. Wireshark

was used to measure the performance of created different networks based on different topologies and conditions.

The continuation of this section focuses on the most relevant literature and state-of-the-art works aimed at addressing the challenges of groundwater monitoring and management, including various technologies and methodologies that have been proposed and implemented to enhance the accuracy, efficiency, and cost-effectiveness of monitoring groundwater parameters. By analyzing these works, specific research gaps and limitations are identified that are addressed by our research. Prior research on traditional and modern groundwater monitoring systems are explored, highlighting the advantages and drawbacks of different approaches. This includes a review of GSM-based systems, which, despite their widespread use, often suffer from high energy consumption and dependency on mobile network coverage. The adoption of emerging technologies such as LoRa which offers promising solutions for remote and low-power applications, is explored as well. The identification of these gaps in existing research informs the design and implementation of our proposed approach, which is detailed in the section called Materials and Methods. Our work builds on the strengths of previous studies while addressing their shortcomings, particularly in terms of energy efficiency, network reliability, and scalability in diverse environmental conditions. By integrating innovative technologies and comparing different network topologies, our study contributes to the advancement of sustainable groundwater monitoring solutions. In our work, we mainly focus on the LoRa module which is like a GSM module to establish wireless communication. Low-power communication has many on-the-shelf choices, but LoRa is one of the best [4][5]. LoRa technology provides a very eye-catching combination of ultra-long distance, low power consumption, and safe data transmission, which can effectively solve the security and stability problems of data communication. In the work done in [6], the authors propose a system utilizing M2M-LoRa technology for monitoring water quality, distribution and pollution control in Smart Village Projects. This system employs LoRa motes and sensors placed in water tanks across 200 locations, allowing continuous monitoring of water quality and levels. The collected data is centrally displayed, facilitating comprehensive control over the water distribution system and enabling the prevention of water wastage and the distribution of polluted water. According to [7], the authors propose using the NuttyFi ESP8266 WiFi board for water level measurement, combining advanced technology with creativity. This system facilitates real-time data transfer and remote monitoring via the Blynk IoT app, allowing users to check water levels globally and control an actuator module. The incorporation of ultrasonic technology enhances the precision and reliability of readings. This system offers a state-of-the-art, user-friendly solution for optimal water management, demonstrating efficient performance with minimal computational costs. The study in [8] developed

an IoT-based automated irrigation system to optimize water usage in agriculture, addressing the critical issue of water scarcity. Temperature and moisture sensors gather data, which is transmitted via a LoRa network to a controller unit for threshold comparison and motor activation or deactivation. The system also utilizes a GSM module to notify users of motor status via SMS and records sensor data and water consumption on Thingspeak for analysis. Research by [9] details a pioneering project by the Department of Fisheries and Aquaculture (DJPB) to model high-density tilapia cultivation, aiming for a stocking density of 25 fish per square meter at 20 ppt salinity. The project's success relies on rigorous water quality management, facilitated by an IoT Smart Water Quality Monitoring System that measures key parameters—temperature, Dissolved Oxygen (DO), pH, salinity, and water volume—providing real-time updates at one-second intervals. The system's initial deployment involves installing 10 units across ponds with surface areas of 4000m² and 2000m².

The authors in [10] designed a LoRa-based IoT network for hydroponic farm monitoring, leveraging IoT advancements for precise wireless data transfer. The system employs various sensors to measure key parameters, with real-time data transmitted via LoRa to a gateway for simultaneous viewing and analysis by authorized users, enhancing monitoring efficiency. This approach capitalizes on LoRa's advantages, including long-distance communication, battery longevity, and noise resistance, making it a superior solution for continuous hydroponic farm oversight.

Based on the work in [11], the authors develop a Fog Server-based irrigation system to enhance smart agriculture by increasing crop yield and reducing water wastage. Their system employs LoRaWAN to relay sensor data to a fog server, using MQTT and Node-Red for micro-service communication. This framework's key advantage is its functionality in areas with intermittent internet connectivity, making it a robust solution for modern agricultural challenges. The findings of [12] present a smart irrigation system utilizing LoRa P2P networks, designed to automate irrigation by learning from expert farmers' experiences. Experimental results indicate the system's high suitability for modern greenhouse agriculture. In [13], the authors developed an Internet-based automation system for plant monitoring, using an Arduino Atmega 328p microcontroller and LoRa 915 MHz to measure water pH, soil pH, and soil moisture, ensuring optimal irrigation in agricultural lands. The system, tested with Pakcoy plants, uses LoRa-integrated water containers to maintain average pH levels, displaying real-time data via the Thingspeak IoT server.

Work done by authors in [14] develops a field management system incorporating a field server and a local wireless network using LoRa to significantly reduce power consumption and maintenance frequency, thus easing

agricultural workloads and facilitating knowledge transfer among Japanese farmers. Experimental results demonstrate effective data transmission between the master unit and field server, with a daily power consumption of 75.36 mW, allowing for theoretical continuous operation of up to 995 days which is sufficient for monitoring rice cultivation. The authors in [15] address the challenges of irrigation monitoring over extensive agricultural lands and under extreme weather conditions by developing an IoT-based system using LoRa. They implement a data communication protocol to efficiently manage multi-node data transmission and accommodate new devices, thereby optimizing communication and expanding the reach of irrigation monitoring. In the research done in [16], authors propose an enhanced tropical peatland Fire Weather Index (FWI) system, integrating groundwater level (GWL) data with the drought code (DC) to better predict fire risk. Utilizing a LoRa-based IoT system for data collection in Raja Musa Forest Reserve in Malaysia, the study verifies the system's efficacy by comparing its data with that of METMalaysia, showing a high correlation of 0.8. A robust IoT-based monitoring and control system aimed at addressing water supply challenges in urban residential areas, emphasizing continuous real-time monitoring for efficient water distribution, supply management, and quality control was proposed by authors in the research [17]. The system utilizes a network of physical items equipped with sensors, software, and network connectivity, enabling remote monitoring and control from anywhere, with data uploaded to the cloud via Adafruit for real-time tracking and management facilitated by efficient client-server communication. The next research given in [18] discusses the critical challenges faced by water supply departments due to decreased rainfall, emphasizing the need for robust monitoring and control systems to address issues such as water distribution, interrupted supply and conservation. The proposed IoT-based approach enables continuous and real-time monitoring of water supply, facilitating efficient management through the integration of sensors, software and network connectivity. An innovative approach was described in [19] which integrates sensors and intelligent algorithms to optimize infrastructure efficiency. Powered by an external Arduino board and GSM module, the system monitors water quality, temperature, turbidity, and pH levels, offering enhanced adaptability and connectivity compared to existing WiFi-dependent models. Simulation results validate its effectiveness, highlighting feasibility and potential impact, while an innovative alert feature notifies users of deviations in water quality parameters, enhancing practicality and responsiveness. This research contributes to the discourse on water infrastructure management, offering a forward-thinking approach to resilient and sustainable practices. Most previous works in this domain have utilized pre-existing server solutions, whereas our approach involves the development of our own server, website and monitoring

system from scratch, thus allowing more customization aimed at enhancing efficiency.

II. MATERIALS AND METHODS

In this section, we outline the detailed methodology and workflow employed in the implementation and evaluation of the underground monitoring system using LoRa technology. The methodology is structured to provide a systematic approach to the setup, deployment, and data transmission of sensor nodes, as well as the establishment of a central gateway for data

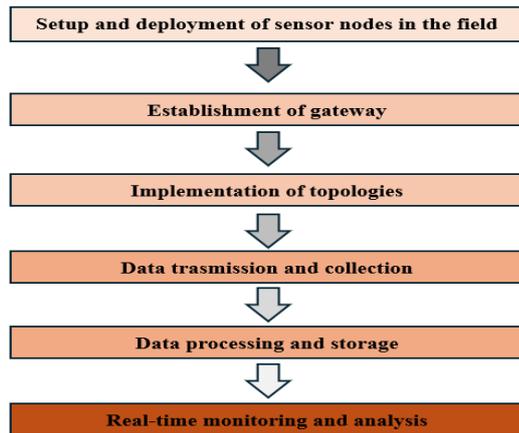


Fig. 1. Workflow.

collection. Following the workflow depicted in Figure 1, we describe the configuration of sensor nodes, their deployment in the field, and the setup of the central gateway. Furthermore, we discuss the implementation of three different LoRa topologies (star, mesh, and line) and their respective advantages and disadvantages. The methodology also covers the data transmission and collection process, including the processing and storage of collected data. Finally, we explain the real-time monitoring and analysis of environmental parameters through a web-based interface.

This comprehensive methodology ensures a clear understanding of the procedures involved in developing and evaluating the underground monitoring system.

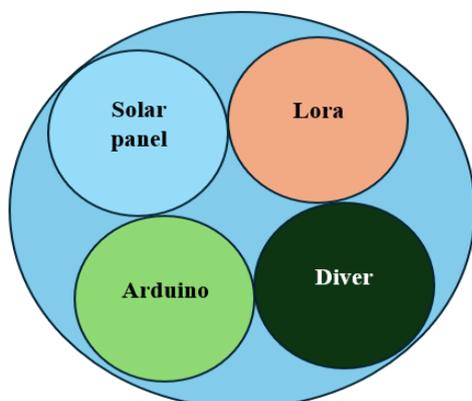


Fig. 1. Node elements.

Each sensor node in the well was meticulously configured to

include an Arduino microcontroller, a LoRa device, and a Diver sensor along with a solar panel to power it up (Fig 2).



Fig. 2. Diver sensor.

The Diver sensor was responsible for measuring water level, salinity, and temperature from groundwater up to 150 meters deep (Fig 3).



Fig. 3. The well equipped with a solar panel.

The collected data was processed and transmitted via LoRa communication for further analysis. Solar panels powered the nodes, ensuring autonomous and sustainable operation. Sensor nodes equipped with solar panels were strategically deployed across various locations within the designated area. Each node was installed in the wells to provide comprehensive coverage and collected environmental data, including water level, salinity, and temperature (Fig 4).

A central gateway was established to gather data from the sensor nodes.

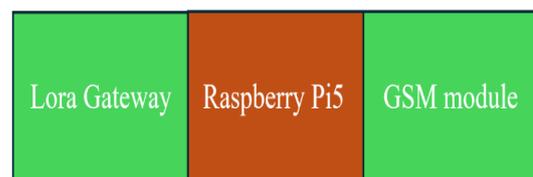


Fig. 4. Main components of gateway.

The gateway consisted of a LoRa gateway, a Raspberry Pi, and a GSM module, enabling long-distance data transmission between GSM modules (Fig 5).

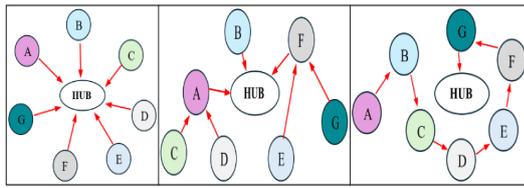


Fig. 5. Star, Mesh and Line topologies (Hub means the gateway)

Three different topologies—star, mesh, and line—were deployed to assess their respective advantages and disadvantages (Fig 6).

Each topology's performance was evaluated in terms of energy consumption, latency, and packet loss. Wireshark, a network protocol analyzer, was used to measure latency and packet loss, and the power consumption of each node was measured as well. The results of each topology are illustrated in the results section.

Sensor nodes transmitted data to the gateway using LoRa communication and the gateway, comprising a LoRa gateway, Raspberry Pi, and GSM device, relayed this data to another secondary Hub equipped with a GSM module for long-distance transmission. This secondary Hub contains GSM and NodeMCU WiFi devices and NodeMCU is connected to an Internet-enabled router and this WiFi module is responsible for sending the data to the server.

Upon receiving data from the gateway, the GSM module relayed the raw data to the Nodemcu WiFi module in the secondary Hub, ensuring it was refined and structured for further analysis. The processed data was then transmitted to the server using Wi-Fi communication via the NodeMCU Wi-Fi module. This module, connected to a Wi-Fi network with internet access, facilitated the swift and reliable transmission of data to the server, where it was securely logged and stored for future reference (Fig 7).

A comprehensive web-based monitoring system was established to visualize and analyse the collected data in real-time.

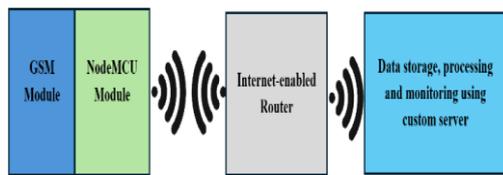


Fig. 6. Sending data to server from secondary Hub.

The web server continuously received data from the NodeMCU Wi-Fi module, accurately logging environmental parameters such as water level, temperature, salinity, and speed of water flow.

The server, along with storing data, processes this data and updates the web interface in real time, providing users with immediate insights into the monitored environment. The user-friendly web interface displays real-time data graphically, showing trends and changes over time. Additionally, it offered detailed historical data, allowing users to review past readings and analyse long-term trends.

This setup facilitated easy tracking, comparison of data, and proactive management based on the collected insights.

III. RESULTS AND DISCUSSIONS

This section presents our comparative analysis of This section presents our comparative analysis of three network topologies—star, mesh, and line—in an automated system for monitoring underground water parameters, focusing on energy consumption, latency, and packet loss. The data reveals the efficiency and reliability of each topology, highlighting their respective advantages and disadvantages. Energy consumption, critical for solar-powered nodes, is illustrated in the table below, showing milliampere-hour (mAh) usage for each node and the gateway across the topologies.

TABLE 1. ENERGY CONSUMPTION COMPARISON

Nodes	Star (mAh)	Mesh (mAh)	Line(mAh)
A	30.4	42.1	28.6
B	35.1	50.4	36.9
C	32.6	26.7	48.2
D	33.8	53.3	59.5
E	37.2	22.8	75.3
F	40.5	67.7	90.7
G	39.7	35.9	102.8
Gateway	109.3	92.0	70.6

The energy consumption analysis of different topologies reveals that the star topology exhibits moderate energy consumption, with the gateway consuming the highest energy due to its central role in data collection and transmission. In contrast, the mesh topology shows higher energy consumption in nodes as a result of the multi-hop communication required, but the gateway itself consumes less energy compared to the star topology. The line topology, however, results in the highest energy consumption for most nodes, especially those close to the gateway since they receive and transmit signal at the same time, which highlights the inefficiencies inherent in long linear communication chains. Also, another disadvantage is that if any node does not work, it may lose connectivity, thus losing the data of other nodes that pass through this node.

Latency is a measure of the time taken for data to travel from a node to the gateway. Lower latency is crucial for real-time monitoring applications. The table below presents the latency in milliseconds (ms) for each node across the three topologies.

TABLE 2. LATENCY

Nodes	Star (ms)	Mesh (ms)	Line(ms)
A	30.3	30.3	905.6
B	35.7	35.7	682.2
C	32.6	71.1	460.8
D	25.6	77.5	349.4
E	23.7	83.9	235.9
F	29.8	95.2	128.3
G	30.5	33.8	45.7

The latency analysis indicates that the star topology maintains low latency due to direct communication between nodes and the gateway. Conversely, the mesh

topology generally exhibits higher latency than the star topology as a result of the additional hops required for data transmission. The line topology, however, suffers from significantly higher latency, particularly for nodes further from the gateway, due to the sequential nature of data transmission.

Packet loss is a critical parameter affecting the reliability of data transmission in sensor networks. Lower packet loss indicates more reliable communication. The table below displays the packet loss percentage for each node across the three topologies.

TABLE 3. PACKET LOSS

Nodes	Star (%)	Mesh (%)	Line (%)
A	5.4	13.7	23.8
B	12.8	15.2	19.6
C	7.1	11.5	15.3
D	11.6	16.8	12.7
E	9.3	12.9	9.1
F	4.7	14.3	6.4
G	7.7	17.4	3.2

The packet loss analysis reveals that star topology exhibits the lowest packet loss overall, benefiting from direct communication paths to the gateway. In contrast, the mesh topology shows moderate packet loss, reflecting the complexity and potential interference inherent in multi-hop communications. The line topology, however, experiences the highest packet loss, particularly for nodes further from the gateway, due to its linear communication path.

Star topology offers several advantages, including low latency, low packet loss, and simpler network management. However, it also has disadvantages such as higher energy consumption at the gateway and a potential single point of failure. In contrast, the mesh topology increases network robustness and redundancy but comes with higher energy consumption due to multi-hop communication and increased latency. The line topology, while advantageous for its simple implementation and minimal management, suffers from high latency and packet loss, particularly as the distance from the gateway increases, as well as higher energy consumption. The results highlight the strengths and weaknesses of each topology in terms of energy consumption, latency, and packet loss. The star topology, while exhibiting low latency and packet loss, faces higher energy demands at the gateway. The mesh topology provides robustness and redundancy but suffers from increased latency and energy consumption. The line topology, despite its simplicity, struggles with high latency, packet loss, and energy inefficiencies.

In addition to the above analysis, it is worth noting that our experimental setup presents avenues for further exploration. The observed variations in energy consumption, latency, and packet loss suggest that while the star topology offers optimal performance in terms of latency and reliability, its inherent energy demands at the gateway may require further optimization. Future work could investigate hybrid network configurations or adaptive protocols that dynamically balance the

advantages of star, mesh, and line topologies, especially in environments with variable interference or node density. Moreover, exploring additional network topologies—such as ring or cluster-based networks—and integrating machine learning techniques for predictive maintenance and traffic management could further enhance system robustness and scalability. This expanded scope could lead to more comprehensive strategies for automated groundwater monitoring, ensuring that the system remains efficient under diverse operational scenarios and weather conditions. Such research directions will not only refine our current approach but also contribute to the development of next-generation monitoring systems tailored for sustainable water resource management in water-scarce regions.

IV. CONCLUSIONS

In this study, we developed an automated system for monitoring underground water at a depth of 150 meters by integrating diver sensors, Arduino processing, LoRa communication and a custom server for real-time data management. Our experimental evaluation, conducted across seven well nodes using star, mesh, and line network topologies, demonstrated that the star topology yields the lowest latency and packet loss, confirming its superiority for real-time applications. Power consumption measurements revealed that, although the star topology imposes higher energy demands on the gateway, the overall system performance clearly validates the efficiency of the proposed approach. Importantly, our results underscore the feasibility of employing LoRa technology as an effective alternative to conventional GSM-based methods, offering improved power efficiency and reduced operational costs. By comparing multiple network configurations, we proved the versatility and performance benefits of using LoRa across varied deployment scenarios, providing a robust foundation for enhanced decision-making in water resource management. Furthermore, future research could advance this work by exploring hybrid network topologies that integrate the strengths of star, mesh, and line configurations. Such approaches could enable adaptive protocols that dynamically respond to varying interference levels and node densities, thereby further enhancing system reliability and efficiency. These innovations promise to extend the applicability of our monitoring system to even more challenging environments. The insights gained through our research pave the way for the development of more efficient and reliable water resource management strategies, thereby contributing to the sustainable utilization of this vital natural resource.

REFERENCES

- [1] “Water shortage may lead to a decrease in GDP of Central Asian countries by 11%,” kun.uz. <https://kun.uz/en/51169440> (accessed October. 10, 2024).

- [2] "Water of Amudarya may decrease sharply due to Kushtepa canal being built by Taliban," kun.uz. <https://kun.uz/en/21230060> (accessed October. 10, 2024).
- [3] "Water scarcity in Uzbekistan: Probable drought and escalating environmental challenges," kun.uz. <https://kun.uz/en/41497711> (accessed October. 10, 2024).
- [4] A. Cano-Ortega and F. Sánchez-Sutil, "Monitoring of the Efficiency and Conditions of Induction Motor Operations by Smart Meter Prototype Based on a LoRa Wireless Network," *Electronics*, vol. 8, no. 9, p. 1040, Sep. 2019, doi: 10.3390/electronics8091040.
- [5] V. K. Sarker, J. P. Queralt, T. N. Gia, H. Tenhunen, and T. Westerlund, "A Survey on LoRa for IoT: Integrating Edge Computing," 2019 Fourth International Conference on Fog and Mobile Edge Computing (FMEC), Jun. 2019, doi: 10.1109/fmec.2019.8795313.
- [6] A. M. Manoharan and V. Rathinasabapathy, "Smart Water Quality Monitoring and Metering Using Lora for Smart Villages," 2018 2nd International Conference on Smart Grid and Smart Cities (ICSGSC), Aug. 2018, doi: 10.1109/icsgsc.2018.8541336.
- [7] A. Dogra, A. Badhouthiya, B. Goyal, K. Kriplani, A. Juyal, and H. Kaur, "Revolutionizing Water Level Monitoring with the Wi-Fi Board," 2024 11th International Conference on Computing for Sustainable Global Development (INDIACom), Feb. 2024, doi: 10.23919/indiacom61295.2024.10498623.
- [8] M. N. Amogha Hegde, M. S. Naik, S. N. Chaitra, M. Madhavi, and A. Ravichandra, "Prediction and Analysis of Water Requirement in Automated Irrigation System using Artificial Neural Network(ANN) and Lora Technology," 2021 IEEE International Conference on Distributed Computing, VLSI, Electrical Circuits and Robotics (DISCOVER), Nov. 2021, doi: 10.1109/discover52564.2021.9663706.
- [9] F. B. G. Pratama, F. Hidayatullah, E. L. I. P. Sari, I. K. A. Enriko, F. N. Gustiyana, and A. Luthfi, "Solar-Powered LoRa Wireless Water Quality Monitoring for Saline Tilapia Aquaculture," 2024 International Conference on Green Energy, Computing and Sustainable Technology (GECOST), Jan. 2024, doi: 10.1109/gecost60902.2024.10474710.
- [10] S. Rathod, S. Dhanan, S. S. Harsha, S. Choudhary, and S. K. P, "LoRa Technology Based Hydroponic Farm Monitoring System," 2021 2nd International Conference on Smart Electronics and Communication (ICOSEC), Oct. 2021, doi: 10.1109/icosec51865.2021.9591729.
- [11] D. Rajasekhar, J. Miao, S. Mishra, S. K. Nayak, and R. Yadav, "Intelligent Irrigation Technique for LoRa Enabled Fog Assisted Smart Agriculture," 2023 IEEE 9th World Forum on Internet of Things (WF-IoT), Oct. 2023, doi: 10.1109/wf-iot58464.2023.10539579.
- [12] Y. C. Chang, T. W. Huang, and N. F. Huang, "A Machine Learning Based Smart Irrigation System with LoRa P2P Networks," 2019 20th Asia-Pacific Network Operations and Management Symposium (APNOMS), Sep. 2019, doi: 10.23919/apnoms.2019.8893034.
- [13] Puput Dani Prasetyo Adi, Dwi Arman Prasetya, Rahman Arifuddin, Angraini Puspita Sari, Fransiska Sisilia Mukti, Volvo Sihombing, "Application of IoT-LoRa Technology and Design in irrigation canals to improve the quality of agricultural products in Batu Indonesia," 2021 2nd International Conference On Smart Cities, Automation & Intelligent Computing Systems (ICON-SONICS), Oct. 2021, doi: 10.1109/icon-sonics53103.2021.9617175.
- [14] T. Hirata, K. Terada, M. Toyota, Y. Takada, K. Matsumoto, and M. S. Tanaka, "Proposal of a power saving network for rice fields using LoRa," 2017 IEEE 6th Global Conference on Consumer Electronics (GCCE), Oct. 2017, doi: 10.1109/gcce.2017.8229298.
- [15] A. Kurniawan, H. Al-Hakim, D. J. Rumala, and I. K. E. Purnama, "LORAPAI: LoRa Routing Protocol for an Agricultural Irrigation System," 2021 International Seminar on Intelligent Technology and Its Applications (ISITIA), Jul. 2021, doi: 10.1109/isitia52817.2021.9502198.
- [16] Lu Li, Aduwati Sali, Jiun Terng Liew, Nur Luqman Saleh, Sharifah Mumtazah Syed Ahmad, Azizi Mohd Ali, "Estimation of Ground Water Level (GWL) for Tropical Peatland Forest Using Machine Learning," *IEEE Access*, vol. 10, pp. 126180–126187, 2022, doi:10.1109/access.2022.3225906.
- [17] Sandhya. A. Kulkarni, V. D. Raikar, B. K. Rahul, L. V. Rakshitha, K. Sharanya, and V. Jha, "Intelligent Water Level Monitoring System Using IoT," 2020 IEEE International Symposium on Sustainable Energy, Signal Processing and Cyber Security (iSSSC), Dec. 2020, doi: 10.1109/issc50941.2020.9358827.
- [18] Md. N. Alam, A. Shufian, Md. A. A. Masum, and A. A. Noman, "Efficient Smart Water Management System Using IoT Technology," 2021 International Conference on Automation, Control and Mechatronics for Industry 4.0 (ACMI), Jul. 2021, doi: 10.1109/acmi53878.2021.9528202.
- [19] J. Janani, A. Sanjeevi Gandhi, S. Aishwarya, and T. Porselvi, "Smart Water Monitoring with GSM Alerts: An IoT Approach," 2024 IEEE International Students' Conference on Electrical, Electronics and Computer Science (SCEECS), Feb. 2024, doi: 10.1109/sceecs61402.2024.10482084.