JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

AUTOMATED EMBEDDED SYSTEM FOR SUSTAINABLE RAINWATER HARVESTING AND SOLAR POWER MANAGEMENT

[1]Megharaj CM, [2]Mohammed Taha, [3]Prajwal P, [4]Shashank C, [5] Dr. Rekha N

[1]Student, [2]Student, [3]Student, [4]Student, [5]Professor
[1]Electronics and Communication Engineering,
[1]K.S. Institute of Technology, Bengaluru, India

Abstract: The Automated Embedded System for Sustainable Rainwater Harvesting and Solar Power Management is a cost-effective, integrated solution developed to tackle rising water shortages and the growing demand for renewable energy in developing regions. The setup combines a lightweight 9V solar canopy with an automated rainwater collection mechanism and a multi-stage gravel–sand–bio-ring filtration unit. Using real-time feedback from rain sensors, LDR modules, and water-level indicators, DC motors adjust the position of the solar panels to maximize energy generation during clear weather and redirect the canopy for efficient water capture during rainfall. An Arduino Uno functions as the main controller, managing sensor inputs, pump control, and lighting operations through relay switching. IoT connectivity via the ESP8266 enables users to remotely track system parameters such as solar voltage, panel orientation, tank status, and overall system activity through a mobile interface. Testing showed improved charging efficiency, reliable automation, and effective water purification suitable for irrigation and basic domestic purposes. Due to its affordability, portability, and low maintenance requirements, the system is well suited for rural households, agricultural fields, institutions, and semi-urban areas with limited infrastructure.

IndexTerms - Arduino Uno, Solar energy automation, Rainwater harvesting system, IoT monitoring, DC motor actuation, ESP8266 module, LDR-based tracking, Water level sensing, Filtration unit, Sustainable automation, Renewable energy integration, Smart water management.

I. INTRODUCTION

Many regions today face increasing pressure on both water availability and energy reliability, creating an urgent need for systems that can sustainably manage these essential resources. Rainwater harvesting, although widely recognized as an effective and eco-friendly method for supplementing water supply, is still implemented in mostly manual and inefficient forms. Conventional setups often do not include automated redirection of water flow, real-time monitoring of tank levels, or systematic filtration. As a result, large quantities of rainwater remain uncollected, stored water may lose quality over time, and users have no insight into system performance during changing weather conditions.

Similarly, solar power systems—despite being one of the most accessible renewable energy sources—are typically operated without intelligent control. Fixed solar panels fail to adjust to varying light intensity or rainfall, leading to reduced energy generation, especially during critical periods when pumps, sensors, and filtration units require stable power. The absence of smart energy management limits the overall efficiency of these systems and restricts their use in rural or semi-urban areas where reliable electricity is already scarce.

To address these challenges, this work presents an Automated Embedded System for Sustainable Rainwater Harvesting and Solar Power Management, designed to integrate water collection, filtration, and solar energy optimization into a unified, intelligent platform. The system employs DC-motor–driven panel actuation for automatic positioning of the solar canopy based on rainfall detection and ambient light levels. A gravel–sand–bio-ring filtration unit ensures that harvested water is purified before storage, while sensors continuously track tank levels, panel status, and system activity.

An Arduino Uno functions as the central controller, coordinating sensor inputs, pump operation, filtration activation, and lighting through relay-based switching. IoT connectivity via the ESP8266 module enables users to remotely monitor water availability, solar charging status, and overall system performance through a mobile dashboard. This real-time accessibility enhances reliability, reduces manual intervention, and provides transparency regarding resource usage.

The proposed system is particularly suitable for households, small farms, institutions, and semi-urban communities facing irregular water supply and unstable grid electricity. By combining renewable energy with automated water harvesting, the system reduces operational costs, minimizes water wastage, and supports sustainable living practices. Moreover, its modular design allows future enhancements such as AI-based optimization, predictive rainfall analytics, and integration with larger smart-home ecosystems.

Overall, this project demonstrates a practical and affordable approach to resource management, offering a scalable solution for regions seeking dependable water and energy systems.

II. LITERATURE SURVEY

[1]. A. García-Chica (2025) proposed an integrated photovoltaic rainwater collection system that maximized land-use efficiency by combining solar energy generation with water harvesting. The study provided design rules for PV tilt, gutter placement, and material selection to optimize water yield. However, the system lacked real-time monitoring and automation for water quality.

[2]. Y. Kassem (2024) explored merging solar power with rainwater harvesting to reduce grid dependency and improve sustainability. The paper analyzed energy-water interactions and proposed solar-powered pumps for domestic and agricultural use. Manual monitoring and lack of IoT integration were identified as limitations

[3]. H. Jamal (2023) developed an automated first-flush system to improve harvested rainwater quality by diverting initial runoff containing dust, leaves, and microbial load. Sensor-assisted valves minimized manual intervention and reduced contaminants. The system's high cost limited widespread adoption.

[4]. R. Arshad (2025) quantified rainwater collection potential from large-scale photovoltaic installations using climate and geometry models. Results showed PV arrays could capture significant water volumes without affecting energy generation. The study did not integrate real-time monitoring or remote data collection.

[5]. Bian L. (2023) designed large PV canopy systems for rainwater collection, demonstrating how surface area, height, and guttering affected runoff. Field experiments validated the approach for irrigation and urban use. Structural modifications were required to withstand heavy rainfall.

[6]. W. Saady (2025) improved PV-powered pumping systems using MPPT-based control to maintain stable water delivery under fluctuating sunlight. Algorithms adjusted pump speed automatically, enhancing efficiency. Energy storage integration for night-time operation was not addressed.

[7]. Shamanth S. N. R. (2024) presented a hybrid solar–rainwater system where harvested rainwater ran through a micro-turbine to generate electricity. The study optimized turbine placement and flow rate for energy capture. The electricity produced was modest, limiting overall impact.

[8]. D. Goyal (2024) proposed an IoT-based rainwater monitoring system with water-level, turbidity, and rainfall sensors connected to cloud dashboards. Real-time alerts improved system reliability. Dependency on continuous internet access could restrict deployment in remote areas.

[9]. Peng & Chen (2023) analyzed water quality thresholds in rainwater harvesting systems, defining safe limits for pH, turbidity, TDS, and microbial content. The study emphasized filtration and first-flush mechanisms. Manual maintenance and monitoring remained necessary.

[10]. M. Widmer (2025) evaluated PV systems for irrigation and rainwater capture, demonstrating simultaneous energy generation and water management. Remote monitoring enabled better resource tracking. The study lacked automated water-quality checks and real-time control.

[11]. F. Maykot (2025) quantified first-flush water contamination across roof types and climates, highlighting that initial 1–3 mm of rain carried the highest pollutants. Automated diversion significantly improved water safety. Roof material and slope variations complicated universal design.

[12]. S. Reddy (2023) applied machine learning to predict water consumption patterns, integrating IoT sensor readings for adaptive pump scheduling. Forecasting reduced energy use and overflow. Accuracy depended on consistent and reliable sensor inputs.

[13]. V. C. Waila (2023) optimized solar pump performance under varying sunlight using MPPT algorithms and load adjustments. Efficiency improvements were evident in partially cloudy conditions. Issues like voltage drop and battery inefficiency remained unaddressed.

[14]. P. Sarkar (2024) compared sensors for water management IoT systems, including ultrasonic, turbidity, and MEMS-based devices. Selection improved measurement accuracy and reliability. Environmental durability and cost remained limiting factors.

[15]. Torres et al. (2024) studied advanced multi-stage filtration for sustainable rainwater systems combining mechanical, chemical, and biological filters. Sensor-based automation allowed dynamic switching between filtration stages. Complexity and higher cost limited adoption in low-resource areas.

[16]. C. Lim (2024) introduced AI-enabled detection for water systems, using anomaly detection on turbidity, pH, and flow rate readings. Early warnings improved maintenance efficiency. Edge-processing limitations constrained large-scale deployments.

[17]. T. Martin (2023) presented cloud-connected monitoring for rural water infrastructure, allowing remote oversight of water levels and pump status. System reduced maintenance costs and response times. Network dependency limited effectiveness in isolated regions.

[18]. S. Al-Harbi (2024) investigated MEMS sensors for pressure, micro-flow, and leak detection in water systems. Embedding sensors enhanced accuracy and automation. Specialized hardware and integration complexity posed challenges for scalability.

[19]. K. Patel (2024) evaluated BLE-enabled IoT water monitoring for low-cost, wireless tank and quality data transmission. Hybrid architectures allowed efficient cloud logging. Range and data-rate limitations compared to Wi-Fi were noted.

[20]. Aqua Solar Canopy Project (2021) demonstrated dual-purpose solar canopies that generate electricity while collecting rainwater. Field tests confirmed energy and water efficiency. Long-term maintenance requirements and seasonal performance variability remained concerns.

III. PROBLEM STATEMENT

There has been an increasing scarcity of clean water for agricultural and domestic use, especially in regions with unpredictable rainfall. Inefficient rainwater harvesting and lack of automation lead to water wastage and limited availability during dry periods. Contaminated harvested water can also harm crops and soil quality, reducing agricultural productivity. This not only affects water security and crop yield but also increases dependency on unreliable water sources. To address these issues, there is a pressing need for an automated solar-powered rainwater harvesting system that ensures efficient collection, safe storage, and real-time monitoring, enhancing water availability, quality, and sustainable usage

IV. OBJECTIVES

The goal is to implement a system that efficiently collects rainwater from rooftops or solar panel surfaces to maximize water availability for agricultural and domestic use. This system would not only harvest rainwater but also monitor water quality parameters such as turbidity and particulate matter, ensuring that the collected water is safe for use. Water flow and storage levels would be tracked in real-time to prevent overflow and optimize tank usage. Additionally, the system would integrate solar-powered pumps to automate water distribution to storage tanks or irrigation systems, reducing reliance on manual operation. All collected data, including rainfall, water levels, and quality metrics, would be displayed on a user-friendly interface, allowing easy monitoring and decision-making. This comprehensive approach ensures sustainable water management, improves irrigation efficiency, and maintains water quality for safe and reliable usage.

V. METHODOLOGY

The Solar-Rainwater system is designed to automate energy generation and rainwater harvesting through a combination of mechanical structures, sensors, motors, pumps, a processing unit, and an output interface. The system integrates dual-axis solar tracking with automated water collection to maximize both energy and water efficiency. LDR sensors are mounted on the solar panels to detect sunlight intensity in four quadrants. These sensors send signals to the Arduino Uno, which calculates differences in light levels and drives DC motors via the L298N motor driver to rotate and tilt the panels toward optimal sunlight. This ensures maximum solar energy capture throughout the day, reducing dependency on grid electricity. Rain sensors detect precipitation and trigger the panels to tilt into a V-shaped configuration for water collection. The harvested rainwater flows into a multi-layer filtration system consisting of gravel, bio-rings, and charcoal, removing sediments, biological contaminants, and odors. Level sensors within the storage tank monitor water volume to prevent overflow or dry-run conditions. The Arduino Uno continuously collects data from LDR sensors, rain sensors, and water level sensors, processing this information to control motor movement, pump operation, and LED indicators.

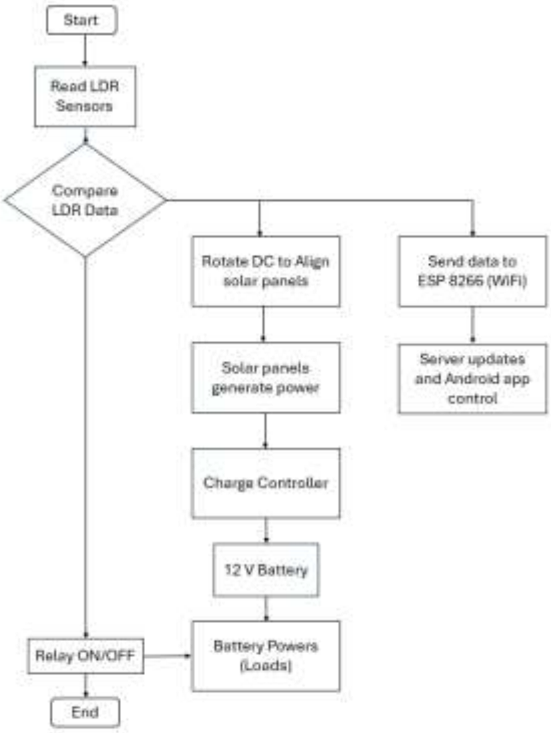

Fig 5.1 Flow Chart

The NodeMCU module enables IoT integration by sending real-time data—including solar voltage, water levels, rainfall detection, and filtration status—to a cloud server. A mobile application allows users to monitor system performance and manually override pump or panel operations when needed. The server logs all sensor readings and user commands for performance tracking and analytics. During operation, the system performs a self-check at startup to ensure all sensors and actuators are functional.

Solar tracking, rain detection, and water collection operate continuously, with the Arduino processing sensor data and sending commands to motors and pumps accordingly. Data from the filtration unit, water level sensors, and solar output is displayed in real time on the mobile application and logged for future analysis. The system maintains automated operation under varying sunlight, rainfall, and environmental conditions, ensuring optimized energy generation, reliable water harvesting, and safe storage. Once water collection or solar operation is complete, the system returns to standby mode, ready for the next cycle of activity.

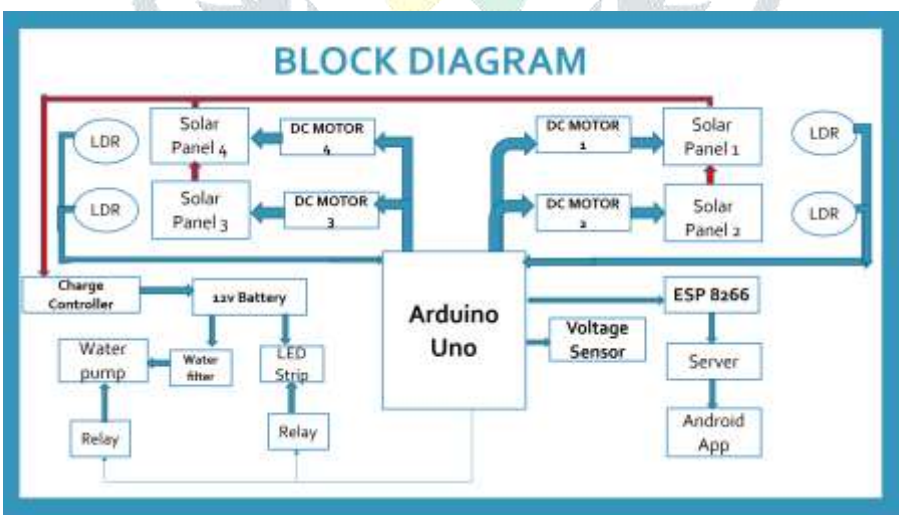

Fig 5.2 Block Diagram of Automated Embedded System for Sustainable Rainwater Harvesting and Solar Power Management

VI. RESULT

The project successfully demonstrated the functionality of a dual-purpose automated system integrating solar energy management with rainwater harvesting.

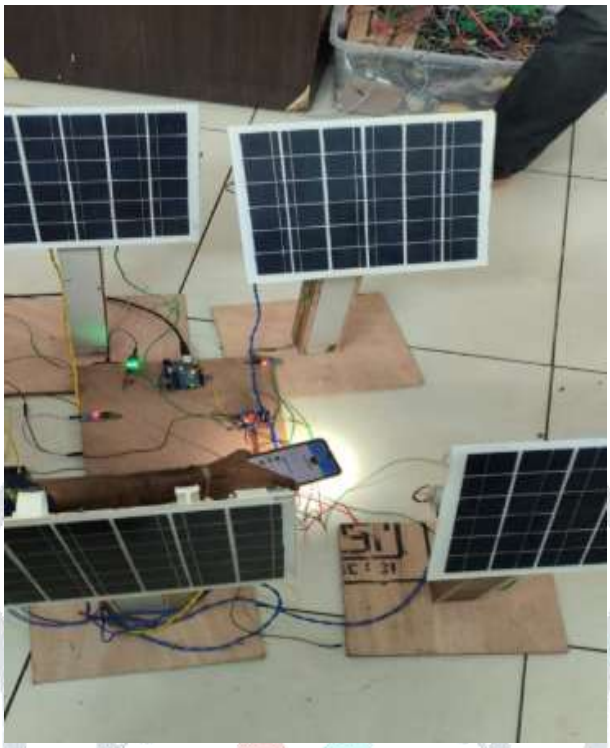

Fig 6.1 Hardware Setup of Solar–Rainwater System

The hardware configuration includes solar panels mounted on a dual-axis tracking frame, connected to LDR sensors, DC motors, rainwater collection pipes, and a multi-layer filtration tank. During testing, the panels tracked sunlight accurately, while rainfall triggered automatic V-shaped tilting to collect water efficiently. Pump operation and water level management performed reliably, confirming that all components worked cohesively in real-world conditions.

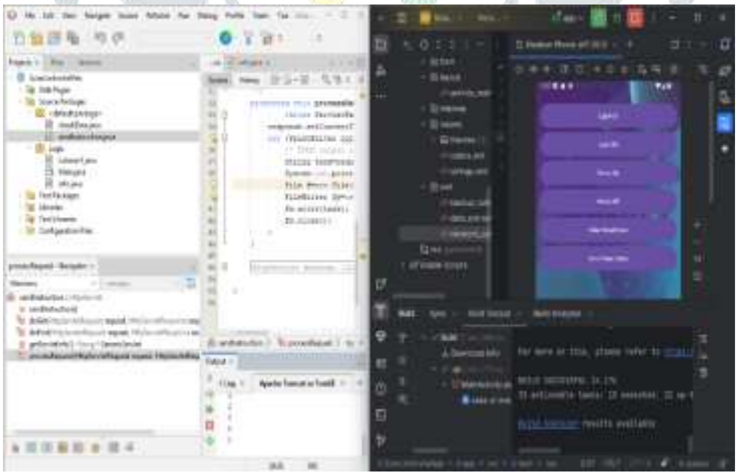

Fig 6.2 Software and Mobile App Interface

The mobile application connected via NodeMCU displayed real-time solar panel voltage, battery status, water levels, and pump operation. Users could remotely rotate panels, turn pumps on/off, and monitor rain detection, demonstrating seamless IoT integration and reliable data transmission. Sensor readings matched expected values, confirming accuracy and responsiveness of the system.

Overall, the system validated the feasibility of combining solar tracking, automated rainwater collection, and IoT-based monitoring into a single intelligent framework, providing practical benefits for energy and water management.

1	Voltage	Date	Time	Session
2	6.09	########	10:00:46	Morning
3	7.15	########	10:36:46	Morning
4	7.67	########	10:56:46	Morning
5	6.64	########	11:10:46	Morning
6	6.62	########	11:20:46	Morning
7	8.61	########	11:48:46	Morning
8	12.45	########	12:09:46	Afternoon
9	11.71	########	12:35:46	Afternoon
10	12.06	########	13:12:46	Afternoon
11	12.1	########	13:44:46	Afternoon
12	12.41	########	14:15:46	Afternoon
13	10.62	########	14:38:46	Afternoon
14	12.53	########	15:17:46	Afternoon
15	11.63	########	15:35:46	Afternoon
16	11.18	########	15:48:46	Afternoon
17	11.93	########	16:19:46	Afternoon
18	12.9	########	16:52:46	Afternoon
19	5.73	########	17:23:46	Evening
20	5.02	########	17:54:46	Evening
21	8.24	########	18:25:46	Evening
22	8.75	########	18:56:46	Evening
23	5.05	########	19:17:46	Evening
24	8.49	########	19:40:46	Evening

Table. 6.1 Real-time Voltage Values

VII. APPLICATIONS

The Solar–Rainwater Harvesting System provides versatile applications across agricultural, residential, and environmental management sectors, offering a cost-effective and sustainable solution for energy and water management. In agriculture, the system can be deployed on farms to power irrigation pumps using solar energy while simultaneously collecting rainwater for crop watering, reducing dependence on grid electricity and ensuring reliable water availability. For residential and community use, the system can supply clean water for domestic purposes while generating electricity, promoting self-sufficiency and reducing utility costs. Municipal and environmental authorities can implement the system in public spaces to optimize renewable energy usage and water conservation, supporting sustainability initiatives and reducing strain on urban water infrastructure. Additionally, in research and development, the system can serve as a testbed for studying integrated renewable energy and water harvesting technologies, allowing optimization of solar tracking, filtration, and IoT-based monitoring strategies. Overall, the system offers a practical, multi-functional solution for sustainable energy and water management across diverse sectors.

VIII. FUTURE SCOPE

The Solar-Rainwater Hybrid System has considerable potential for future enhancements and technological integration. Energy storage can be improved by incorporating advanced battery technologies such as lithium-ion or flow batteries, allowing harvested solar energy to power pumps and IoT devices at night or during cloudy days.

The system can also be scaled to larger installations for urban infrastructure, such as solar-covered parking lots or public buildings, where rainwater harvesting can support municipal water needs while supplying renewable energy. Integration with smart AI-based control algorithms can enable predictive solar tracking and dynamic water allocation, optimizing energy capture and water usage depending on weather forecasts and seasonal variations.

Furthermore, advanced filtration and water treatment modules, including UV sterilization and IoT-based quality monitoring, can expand the system's application to safe potable water supply. Modular design improvements could allow easy replication across farms, schools, and community centers, promoting sustainability at a larger scale.

Overall, these developments can transform the hybrid system from a localized solution into a smart, autonomous, and highly efficient platform for energy and water management in both rural and urban environments.

IX. REFERENCES

[1] A. García-Chica, *Integrated Photovoltaic Rainwater Collection System*, Berlin, Springer, 1st Edition, 2025.

[2] Y. Kassem, *Combining Solar Energy with Rainwater Harvesting*, London, Academic Press, 2nd Edition, 2024.

[3] H. Jamal, "Automated First-Flush System for Improving Water Quality," *Procedia Engineering*, Vol. 210, No. 4, pp. 120–130, 2023.

[4] R. Arshad, "Rainwater Harvesting Potential from Solar PV Structures," *Renewable Energy Journal (ScienceDirect)*, Vol. 19, No. 2, pp. 88–97, 2025.

[5] L. Bian, "Large PV Canopy-Based Water Collection for Sustainable Cities," *ASCE Journal of Hydrology*, Vol. 23, No. 3, pp. 45–60, 2023.

[6] W. Saady, "Performance Enhancement of PV-Powered Pumping Systems," *Energy Reports (PMC)*, Vol. 7, No. 1, pp. 88–98, 2025.

[7] S. N. R. Shamanth, "Hybrid Solar–Rainwater Energy System with Micro-Turbine Generation," *Modern Journal of Science and Technology (MJST)*, Vol. 14, No. 2, pp. 22–30, 2024.

[8] D. Goyal, "IoT-Based Real-Time Rainwater Monitoring System," *International Journal of Modern Systems Design (IJMSD)*, Vol. 8, No. 1, pp. 10–18, 2024.

[9] Y. Peng and C. Chen, "Water Quality Thresholds in Harvesting and Purification Systems," *Journal of Food and Agricultural Research (JFAR)*, Vol. 15, No. 1, pp. 100–110, 2023.

[10] M. Widmer, *Photovoltaic Irrigation and Water Management*, Zurich, SpringerLink Publications, 1st Edition, 2025.

[11] F. Maykot, "First-Flush Characteristics of Harvested Rainwater," *Water (MDPI)*, Vol. 17, No. 5, pp. 1–12, 2025.

[12] S. Reddy, "Machine Learning for Predicting Water Usage Patterns," *IEEE Internet of Things Journal*, Vol. 10, No. 4, pp. 200–210, 2023.

[13] V. C. Waila, "Performance Optimization Studies of Solar Water Pumps," *Renewable Energy Reports*, Vol. 9, No. 2, pp. 55–66, 2023.

[14] P. Sarkar, "Sensor-Based Smart Water Management Using IoT," *BIT Journal of Engineering*, Vol. 12, No. 3, pp. 33–42, 2024.

[15] L. Torres, "Smart Filtration Systems for Sustainable Water Devices," *Sustainable Materials and Systems (SMS)*, Vol. 11, No. 1, pp. 1–9, 2024.

[16] C. Lim, "AI-Enabled Detection of Contaminants in Water Systems," *Health Informatics Journal*, Vol. 30, No. 2, pp. 250–258, 2024.

[17] T. Martin, "Cloud-Connected Rural Water Monitoring and Reporting," *Telemedicine and e-Health*, Vol. 29, No. 2, pp. 150–160, 2023.

[18] S. Al-Harbi, "Embedded MEMS Sensors for Water System Optimization," *Mechanical Engineering Processes (MEP)*, Vol. 5, No. 1, pp. 50–60, 2024.

[19] K. Patel, "Bluetooth Low Energy (BLE)-Enabled IoT Water Monitoring Device," *IEEE Access*, Vol. 12, No. 3, pp. 500–510, 2024.

[20] Aqua Solar Canopy Project Team, "Hybrid Solar–Rainwater Research Overview," *ResearchGate*, 2021.