IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Impact Factor 8.311 ⵘ Peer-reviewed & Refereed journal ⵘ Vol. 12, Issue 5, May 2025

DOI: 10.17148/IARJSET.2025.125387

Automated Embedded System for Sustainable Rainwater Harvesting and Solar Power Management

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

Student, Electronics and Communication, K.S. Institute of technology, Bangalore, India[1-4]

Professor, Electronics and Communication, K.S. Institute of technology, Bangalore, India[5]

Abstract: To address the growing need for water and energy in a sustainable and economical way, it is important to explore alternative, simpler technologies for conserving water and harnessing solar energy. Rainwater harvesting stands out as one of the most effective approaches to meet these needs. This project focuses on the technical side of rainwater collection from agricultural lands. Initially, necessary information such as catchment area sizes and rainfall data is gathered. Based on this, the water harvesting potential is calculated, and an appropriate tank design and capacity are determined.

The study also covers the design and analysis of gutters, as well as systems for first flush and filtration. A specially designed pot-shaped umbrella structure is proposed for installation in agricultural fields. This structure will not only help conserve space but it also allows for dual use: collecting rainwater and generating solar power. During the rainy season, water accumulates in the umbrella structure. Each unit is designed to hold a specific maximum volume of water, with any excess being directed to storage tanks for later use. Additionally, solar panels installed on the umbrella can significantly enhance solar energy generation. As part of the project, an estimation of runoff volumes in the agricultural area is conducted, along with an evaluation of current shortcomings, so that necessary improvements can be implemented.

Keywords: Solar energy, Rain water harvesting, Agriculture

I. INTRODUCTION

Water scarcity is becoming a major global challenge, especially in India, where fast-paced urban growth and rising population numbers have put enormous stress on available water supplies. Although around 70% of the Earth's surface is covered by water, only about 2.5% is freshwater, and just 1% of this freshwater is readily accessible to people. The majority is locked away in glaciers, ice caps, and deep underground aquifers. Even though the total amount of freshwater on Earth has stayed the same over time, the sharp rise in population has led to a significant shortage. Today, both cities and villages are experiencing water crises caused by environmental changes, shifting weather patterns, and poor management of water resources. Environmental shifts have disturbed natural rainfall cycles, making water availability irregular and unreliable. Although rainfall still provides a considerable amount of water, much of it is wasted due to insufficient systems for collection and storage. Addressing this urgent problem demands creative technologies that can not only be capture and store rainwater effectively but also offer additional benefits to society.

To meet this challenge, we have designed an innovative device known as the **"Ulta Chaata using solar panels".** Inspired by the shape of an upside-down umbrella, this groundbreaking invention addresses both need for the reliable water supplies and the growing demand for the renewable energy in cities. The Ulta Chaata serves a dual function: it gathers and purifies rainwater during the rainy season and captures solar energy during dry periods. The working principle behind the Ulta Chaata is simple yet highly effective. During rainfall, water is collected on the broad surface of the inverted umbrella. Initial filtration occurs through a fine mesh with around **2,000-micron pores**, which removes large debris like leaves and soil. The water then passes through a second, finer **20-micron filter** located within the pole of the structure, ensuring even smaller particles are removed before the water reaches the storage tank.

After collection, the water stored in the tank goes through a complete purification process, making it safe for uses like drinking, cooking, sanitation, and irrigation. This system not only helps conserve water but also decreases dependence on municipal water supplies, easing the pressure on city water systems. In addition to rainwater harvesting, the Ulta Chaata is fitted with solar panels that generate electricity from sunlight during dry seasons. The photovoltaic panels integrated into the structure transform solar energy into usable electricity, providing a clean and sustainable source of

DOI: 10.17148/IARJSET.2025.125387

power. This makes the Ulta Chaata a dual-purpose, eco-friendly innovation that addresses critical shortages of both water and energy. The Ulta Chaata with solar panels offers a powerful and practical solution for sustainable development in urban and rural settings alike. By combining water collection and renewable energy generation into a single system, it addresses some of India's most urgent environmental challenges. Expanding the use of such technologies could significantly improve water availability, lower energy costs, and raise the living standards for millions of people.

In summary, with the rising demand for both water and energy, innovations like the Ulta Chaata are essential to building a more sustainable, resilient future. By tapping into natural resources through intelligent, eco-friendly design, we move closer to ensuring that clean water and renewable energy are available to everyone.

II. LITERATURE SURVEY

The study by Tekendra P. Ra, Niroj Aryal, et al **[1].** presents a cost-effective design combining rainwater harvesting with solar-powered pumps. It uses ferrocement tanks for affordable water storage and HDPE pipes for efficient water transport. The system ensures a continuous water supply without relying on the electricity grid, making it ideal for rural areas. Features like first flush systems and optimized catchment designs improve water quality and collection. The paper highlights the system's benefits for reducing costs, supporting agriculture, and promoting environmental sustainability.

The study by Seyfi Şevik and Ahmet Aktaş **[2]** conducted a study on integrating rainwater harvesting into a 600-kW solar photovoltaic (PV) power plant. Their research was presented at the ISPEC 7th International Conference on Agriculture, Animal Sciences, and Rural Development in September 2021. The study focuses on utilizing the large surface area of solar panels to collect rainwater efficiently. Collected water can be stored and used for agricultural or other rural needs. The authors highlight the dual benefit of generating renewable energy while simultaneously conserving water resources. The implementation was found to be technically feasible and cost-effective. Their work shows the potential for large-scale solar farms to support sustainable water management. This approach promotes an integrated model for renewable energy and water conservation in rural development projects.

The research by Duke Mensah Bonsu Antw**i [3],** Isaac Kwadwo Amankwaa, and colleagues conducted a survey on the adoption of rainwater harvesting systems in Ghana. Published in July 2024 in the *Journal of Applied Science Engineering Technology and Management*, the study emphasizes the growing need for alternative domestic water sources. It explores public awareness, acceptance, and the challenges of implementing rainwater harvesting. The results will show that many households are open to using harvested rainwater to supplement their water supply. The study highlights the importance of promoting rainwater harvesting as a sustainable solution to water scarcity. It also suggests policy support and public education to enhance adoption rates.

The study by Aminata Kanta, Rachid Outbib, and Lounes Tadrist (December 2023) [4]a presents a sizing model for solar-powered water pumping systems tailored for sub-Saharan regions. It addresses the challenges of limited energy access and clean water availability in rural communities. The model is designed to optimize the use of available solar energy while minimizing system costs. By aligning energy supply with specific water usage needs, the proposed approach ensures both efficiency and affordability. This research supports the development of sustainable water management solutions in underserved areas.

The study by Tesfaye Tereche Jara, Ayodeji Olalekan Salau, and colleagues (September 2024) [5] "Optimization of a Fuzzy-Based MPPT Controller for a PV Water Pumping System Through a PSO-Based Approach" introduces a fuzzy logic-based MPPT controller for photovoltaic (PV) water pumping systems. To enhance performance, the controller is optimized using a Particle Swarm Optimization (PSO) algorithm. The research demonstrates significant improvements in tracking efficiency and system reliability, especially under fluctuating solar irradiance and temperature conditions. This optimized approach ensures maximum energy extraction from the PV system. Overall, the study contributes to the development of smarter and more resilient solar-powered water pumping solutions.

The study by Mohammed Benzaouia, Hajji Bekkay, and colleagues (August 2021) [6] "Energy Management Strategy for an Optimum Control of a Standalone Photovoltaic Batteries Water Pumping System for Agriculture" Applications proposes an optimized energy management and control strategy for standalone photovoltaic (PV)-battery water pumping systems used in agriculture. The strategy focuses on addressing key issues such as battery discharge and fluctuations in solar irradiance. By effectively managing energy flow between the PV panels, batteries, and water pump, the system ensures a stable and continuous water supply. The approach enhances system reliability and performance in off-grid agricultural settings. This research supports sustainable and efficient water management in areas with limited access to electricity.

DOI: 10.17148/IARJSET.2025.125387

The hybrid solar-rainwater harvesting system **[7],** as proposed by Shamanth Showri N R et al. (2024), presents a novel approach by combining solar power with rainwater collection channels and mini turbines for electricity generation. This system aims to maximize energy output in areas where sunlight and rainfall are abundant, making it a sustainable solution for both water and energy needs. Previous studies have been focused on solar-powered water pumping systems and rainwater harvesting independently. It suggests that such hybrid systems could provide a reliable, off-grid solution for rural and semi-urban communities, reducing reliance on conventional energy sources.

The study by Solar photovoltaic powered water pumping systems [8]. Shrey Verma, S. Mishra, and S. Chowdhury conducted a comprehensive review highlighting the key components, working principles, and various applications of these systems. Their study emphasizes the significant benefits of solar PV pumps, such as lower operational costs, minimal maintenance requirements, and substantial reductions in carbon emissions. The review also points out the growing adoption of solar water pumps in agricultural and rural sectors, where access to grid electricity is limited. Overall, the study supports the wider deployment of solar PV pumping systems as a cost-effective and eco-friendly solution for water management.

The study by Rakhi Sharma, Shivanshu Sharma [9], and Sumit Tiwari (2019) conducted a study focusing on the design optimization of the solar PV water pumping systems using the PVsyst 5.52 simulation tool. Their research highlights the critical role of selecting appropriate system components, such as solar panels, pumps, and controllers, to enhance system efficiency. The study also emphasizes the need to factor in local climate conditions like solar irradiance and temperature for achieving consistent performance. By optimizing these parameters, the system can provide a more economical and reliable water supply solution, particularly in rural and agricultural regions. Their findings will contribute valuable insights into improving the feasibility and sustainability of solar-powered irrigation systems.

The study by Anjanee Kumar Mishra and Bhim Singh [10] (2021) proposed a solar-powered water pumping system driven by the switched reluctance motor (SRM) combined with battery energy storage. Their study highlights the use of a bidirectional DC-DC converter, which enables efficient charging and discharging of the battery to maintain system stability. The integration of maximum power point tracking (MPPT) ensures that the system operates at optimal efficiency despite variations in solar irradiance. This design provides a reliable and continuous water supply, making it particularly useful in regions with inconsistent sunlight. The research demonstrates how advanced control strategies which can be significantly enhance the performance and dependability of the solar water pumping systems.

The study by [11] Utkarsh Sharma and Bhim Singh (2020) [11] investigated a utility-tied solar Photo voltaic water pumping system designed to meet both domestic and agricultural water needs. Their research focuses on the integration of solar energy with the utility grid, using an induction motor drive to improve overall system performance. The study discusses important factors such as power quality, system reliability, and operational efficiency under varying solar conditions. By connecting to the grid, the system ensures a continuous water supply even when solar energy alone is insufficient. This approach highlights the potential of hybrid systems to enhance energy reliability and support sustainable water management solutions.

The study by Vipan Chand Waila, Abhishek Sharma, and colleagues (April 2023) [12] employs Response Surface Methodology (RSM) to optimize the performance of the solar (PV) water pumping systems. It identifies critical factors such as solar irradiance, pump load, and panel tilt angle that influence system efficiency. By applying a statistical modeling approach, the research provides the valuable insights into improving the design and operational parameters of PV water pumps. The optimized configurations lead to enhanced energy efficiency and water output. This work offers a practical framework for maximizing the effectiveness of solar-powered irrigation systems.

III. PROBLEM IDENTIFICATION

- Critical shortage of accessible freshwater and reliable power sources due to **population growth** and **urbanization.**
- **Significant rainwater wastage** because of poor storage and harvesting systems.
- Urban issues like **drainage clogging, road flooding,** and **declining groundwater levels.**

Proposed Solution:

- Introduction of the **"Reverse Umbrella"** device.

DOI: 10.17148/IARJSET.2025.125387

Key Features of the "Reverse Umbrella":

- **Captures rainwater** effectively.
- **Purifies** the collected rainwater for usable purposes.
- **Harnesses solar energy** to generate power.

IV. OBJECTIVES

- **Rainwater Harvesting:** Collecting rainwater to reduce water shortages, minimize runoff, prevent flooding, and increase the water table.
- **Solar Energy Utilization:** Using solar power to improve sustainability, enhance energy access, and reduce dependence on conventional energy sources.
- **Eco-friendly Infrastructure:** Developing infrastructure for water purification, energy generation, and mobile charging, supporting agricultural activities in a sustainable manner.

V. METHODOLOGY

This is based on a dual-module system that combines Rainwater Harvesting (RWH) and Solar Energy Harnessing (SEH), with automation and sustainability at its core.

For Rainwater Harvesting, four solar panels are installed on a flexible, inverted canopy. When a rainfall sensor detects rain, a servo motor rotates the panels by 90 degrees, creating a concave shape that captures the rainwater. The collected rainwater flows through gutters, passes a two-stage mesh filtration system (with 2000µm and 20µm filters), and then through sand filters before being stored in underground tanks with overflow control mechanisms. This filtered water can be used for drinking, irrigation, and cleaning, which helps reduce water runoff and wastage.

In terms of Solar Energy Harnessing, the same solar panels are adjusted during dry conditions to maximize sunlight capture, achieving about 15.6% efficiency. The solar energy collected charges batteries that support LED lighting, mobile device charging, and even electric vehicle (EV) charging stations. An automated system smartly switches between rainwater harvesting and solar energy harnessing based on the weather, ensuring continuous and efficient use of resources.

For infrastructure and integration, these units are installed in locations such as parking lots, bus stops, farms, and open spaces, offering shade, clean water, and renewable energy. The modular design allows easy scalability across university campuses and rural areas. Additionally, the system is designed for minimal maintenance while delivering long-term environmental benefits.

DOI: 10.17148/IARJSET.2025.125387

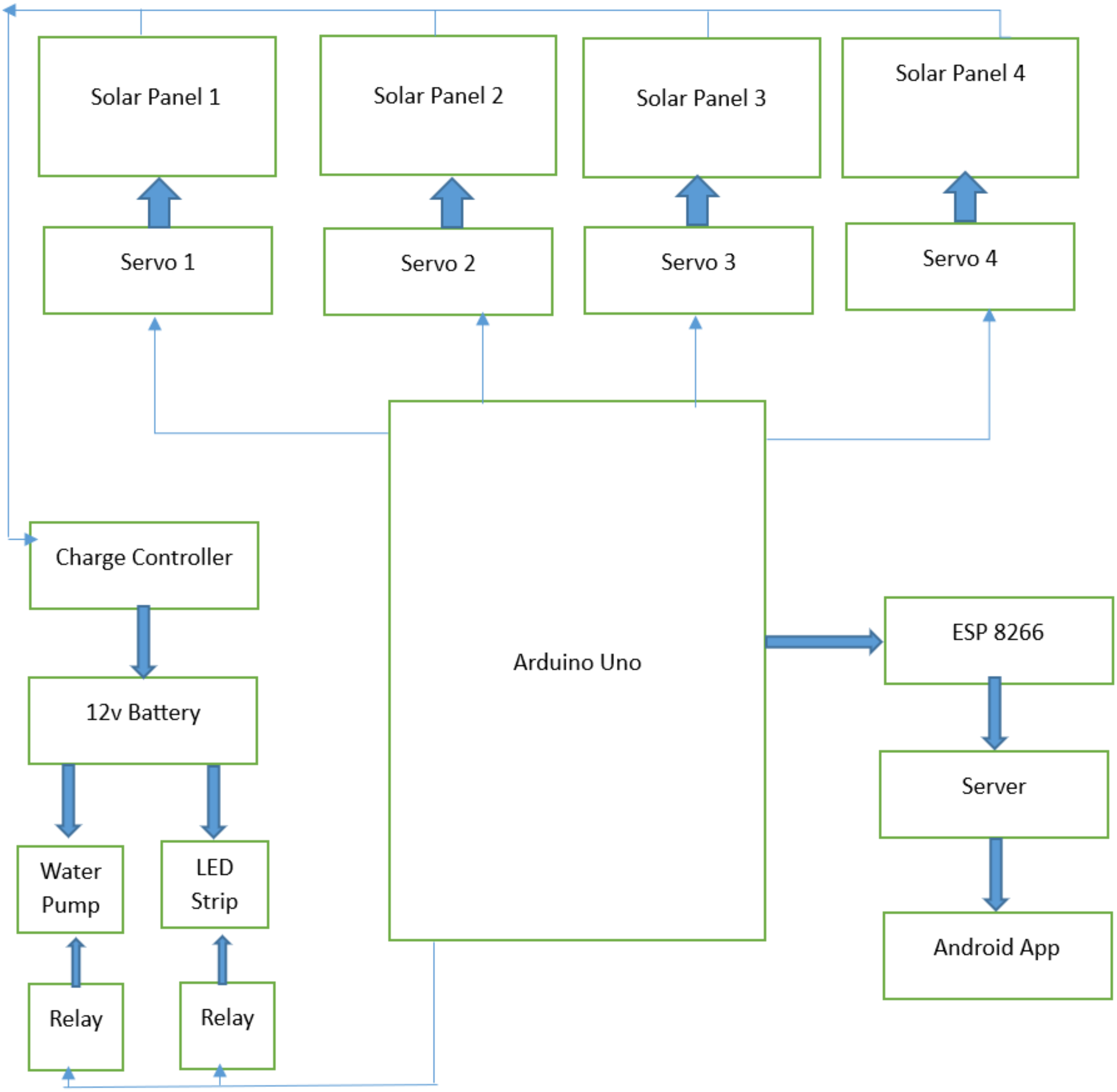

Fig 1. Block Diagram

VI. APPLICATIONS

- **Rainwater Collection**
  Gathers and cleans rainwater for drinking, farming, and sanitation purposes.
- **Solar Power Production**
  This Generates electricity for lighting, device charging, and other everyday needs.
- **Applications in Urban and Rural Areas**
  Reduces flooding and enhances public facilities, farms, and educational campuses.
- **Eco-Friendly Farming**
  Delivers water for crop irrigation and provides solar energy to support agricultural activities.
- **Use in Disasters and Remote Locations**
  Ensures access to clean water and electricity where traditional infrastructure is unavailable.
- **Smart Cities and Sustainable Development**
  Promotes green energy solutions and helps achieve eco-friendly urban growth targets.

DOI: 10.17148/IARJSET.2025.125387

VII. CONCLUSION AND FUTURE SCOPE

The reverse umbrella-style rainwater harvesting system offers an affordable way to provide clean water, renewable energy, and environmental shading. Each unit requires only about 1 square foot of space and can collect up to **1,000 liters** of rainwater during the monsoon season. In addition to water collection, the system can also generate solar power, reaching a maximum output of **1 kW**, depending on weather conditions and the efficiency of the solar panels. By installing multiple reverse umbrella units across agricultural lands, this project aims to capture and conserve every possible drop of rainwater and surface runoff. Overall, the reverse umbrella presents an eco-friendly, energy-saving solution to address both water scarcity and energy needs, supporting our vision to make the **CIT campus** a model of sustainability.

- **Wider Application in Urban and Rural Areas:**

The system can be deployed extensively in smart cities, farming communities, parks, educational institutions, and residential complexes to optimize rainwater collection and solar energy utilization.

- **Incorporation of Smart IoT Technologies:**

Integrating IoT devices can enable features like real-time water quality tracking, automated adjustment of solar panels, and early detection of system faults for efficient maintenance.

- **Expansion for Industrial and Commercial Sectors:**

Larger-scale models can be developed to cater to the needs of factories, shopping malls, warehouses, and office spaces, helping to meet their significant water and energy requirements sustainably.

- **Development of Hybrid Energy Systems:**

The setup can be enhanced by combining the solar energy harvesting with other renewable sources like small-scale wind turbines, ensuring a continuous and reliable supply of green energy.

- **Enhancement of Water Treatment Processes:**

Advanced purification methods, such as UV treatment and membrane filtration, can be incorporated to produce safe, drinkable water even when facing high levels of environmental contaminants.

REFERENCES

[1] Tekendra P. Ra, Niroj Aryal, "The Study of Rain Water Harvesting Technique and Use of Solar Power Pump" Authors et al. Published: December 2022, Jain University.

[2] Seyfi Şevik, Ahmet Aktaş "Rainwater Harvesting in a 600 kW Solar PV Power Plant" Conference: ISPEC 7th International Conference on Agriculture, Animal Sciences, and Rural Development, September 2021

[3] "A Survey on the Need to Incorporate Rainwater Harvesting Systems" as an Alternative Domestic Water Source in Ghana Authors: Duke Mensah Bonsu Antwi, Isaac Kwadwo Amankwaa, et al. Published: July 2024, Journal of Applied Science Engineering Technology and Management

[4] Aminata Kanta, Rachid Outbib, Lounes Tadrist. "Optimal Design of a Solar Pumping System"Published: December 2023

[5] "Optimization of a Fuzzy-Based MPPT Controller for a PV Water Pumping System Through a PSO-Based Approach" Authors: Tesfaye Tereche Jara, Ayodeji Olalekan Salau, et al. Published: September 2024

[6] "Energy Management Strategy for an Optimum Control of a Standalone Photovoltaic-Batteries Water Pumping System for Agriculture Applications" Authors: Mohammed Benzaouia, Hajji Bekkay, et al. Published: August 2021

[7] "Hybrid Solar-Rainwater Harvesting System with Mini Turbine Integration" Authors: Shamanth Showri N R, Sathvik V. Koushik, et al. Published: 2024, Manipal Journal of Science and Technology

[8] "Solar PV Powered Water Pumping System:" – A Review Authors: Shrey Verma, S. Mishra, S. Chowdhury, et al. Published: [Date not specified], ResearchGate

[9] "Design Optimization of Solar Photo Voltaic Water Pumping System" Authors: Rakhi Sharma, Shivanshu Sharma, Sumit Tiwari Published: 2019, Materials Today: Proceedings.

[10] "Solar-Powered Switched Reluctance Motor-Driven Water Pumping System with the Battery Support" Authors: Anjanee Kumar Mishra, Bhim Singh Published: 2021, IET Power Electronics

[11] "Utility-Tied Solar Water Pumping System for Domestic and Agricultural Applications" Authors: Utkarsh Sharma, Bhim Singh Published: 2020, Journal of The Institution of Engineers (India): Series B

[12] "Solar Photovoltaic Water Pump Performance Optimization by Using Response Surface Methodology" Authors: Vipan Chand Waila, Abhishek Sharma, et al. Published: April 2023.