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SolarSense: An loT-Based Smart Irrigation and Fertilizer System

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***Abstract*—-This paper introduces a solar-powered smart drip irrigation and fertilizer management system designed to make farming more intelligent and resource-efficient. The system employs IOT-enabled soil and nutrient sensors that continuously assess field conditions, while a microcontroller regulates water and fertilizer flow with high precision. Powered by renewable solar energy, the setup operates independently of the grid, ensuring sustainability in rural and off-grid areas. Sensor data and system performance will visualized through a realtime loT dashboard, enabling remote supervision and decision-making. The proposed model significantly reduces water and nutrient waste, minimizes manual labor, and enhances crop productivity, establishing a step forward toward self-sustaining smart agriculture.**

***Index Terms*—IoT, Smart Irrigation, Solar Energy, Precision Farming, Automation, Sustainable Agriculture**

I. Introduction

Agriculture remains the backbone of many economies, yet it faces growing challenges due to climate variability, water scarcity, and inefficient resource management. Traditional farming practices often rely on manual monitoring and fixed irrigation schedules, which can lead to over-irrigation, under-irrigation, and excessive use of fertilizers. These inefficiencies not only reduce crop productivity but also contribute to soil degradation and water pollution. To address these challenges, the integration of Internet of Things (IoT) technologies into agricultural systems has emerged as a promising solution for achieving precision farming and sustainable agricultural practices. **SolarSense:** An IoT-Based Smart Irrigation and Fertilizer System aims to optimize the use of water and nutrients by leveraging real-time data collection, automated control, and renewable energy sources. The system employs a

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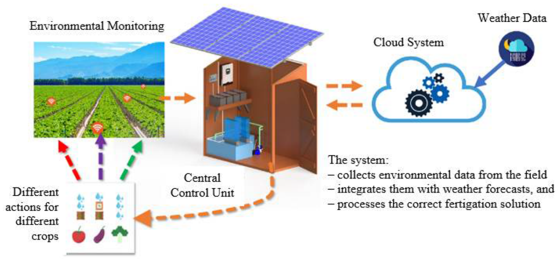

Fig. 1: Features of Smart Irrigation System

network of IoT sensors to continuously monitor environmental parameters such as soil moisture, temperature, humidity, and nutrient levels. These data are analyzed to make intelligent decisions about irrigation timing and fertilizer dosage, ensuring that crops receive the right amount of resources at the right time. To enhance sustainability, the entire system is powered by solar energy, reducing dependency on conventional power sources and enabling operation in remote or off-grid agricultural regions.

By integrating IoT, automation, and renewable

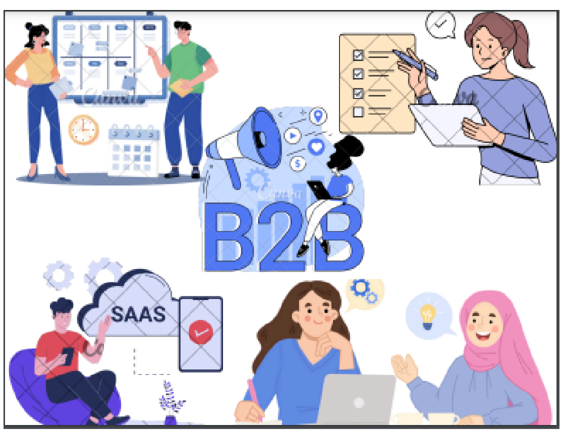

Fig. 2: Iot based smart irrigation system

energy, SolarSense not only improves resource efficiency and crop yield but also supports environmentally responsible farming. This research explores the design, implementation, and performance evaluation of the SolarSense system, demonstrating how IoT-driven smart agriculture can transform traditional farming into a more efficient, datadriven, and sustainable enterprise

Research Objectives

The main objectives of this research are:

O1: To develop an automated irrigation and fertilizer system using IoT technology.

O2: To utilize solar energy as a renewable power source for uninterrupted system operation.

O3: To monitor real-time environmental parameters such as soil moisture, temperature, and humidity for precision irrigation.

O4: To optimize water and fertilizer usage, reducing wastage and enhancing crop yield.

II. Literature Review

1.Singh et al. (2019) developed a solar-based irrigation setup that automatically pumped water to crops using soil moisture sensors. Their system successfully reduced manual effort and ensured timely irrigation. However, their work lacked remote monitoring features, which limits scalability in modern smart-farming needs. Our study enhances this by integrating IoT control and real-time monitoring via mobile interface.

2.Gupta and Sharma (2020) proposed an automated watersupply mechanism using Arduino and drip-irrigation technology. Their model significantly improved water conservation but did not include renewable power support. We address this gap by powering the system with solar energy, making it suitable for rural off-grid locations.

3. Rahman et al. (2021) focused on sensor-based irrigation to improve soil moisture stability. Although the system delivered good accuracy, it required constant electricity, which is expensive for farmers. Our approach uses solar panels to make the solution cost-effective and sustainable.

4.Patel and Verma (2020) designed an IoT-based farm monitoring unit that allowed farmers to observe humidity and temperature through a smartphone. Their system lacked automation for water control. Our research combines IoT monitoring and automatic irrigation to reduce human dependence.

5.Khan et al. (2022) explored machine-learning techniques to predict irrigation schedules based

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on weather data. While effective, their model demanded high computing power. Our design instead utilizes simple threshold-based logic, making it affordable for small-scale farmers.

6.Mehta and Bansal (2021) reported that traditional irrigation wastes 40systems. However, their work did not investigate solar applications. Inspired by this, we introduce solar panels into automation to reduce electricity bills and promote green farming.

7. Joseph et al. (2023) introduced GSM-based control for irrigation pumps. While their model enabled remote pump activation, GSM technology had network limitations in rural areas. We address this by using WiFi and cloud-based IoT services for wider accessibility.

8.Das and Rani (2020) tested various soil sensors and concluded that capacitive moisture sensors perform better than resistive ones in long-term usage. Their research guided our selection of reliable sensors to ensure system durability in farm environments.

9.Fernando and Lopez (2022) demonstrated solar water pumping systems for community farming. Their work proved solar viability but offered no individual cropbased irrigation control. We extend their concept by providing plant-level watering using automated valves.

10.Chauhan et al. (2021) highlighted farmer challenges like high electricity cost and irregular water supply. While they recommended renewable solutions, they did not provide a working prototype. Our research contributes an actual implemented model combining solar energy, sensors, and IoT features.

III. Proposed Methodology

The proposed methodology for the SolarSense: An loT-Based Smart Irrigation and Fertilizer System focuses on automating the irrigation and fertilization processes using real-time sensor data and renewable energy. The system integrates solar power, loT sensors, and a microcontroller to monitor environmental parameters and optimize water and nutrient usage efficiently

Author & Year	Technique Used	Power Source	Communication Tech	Automation Level	Limitation	Gap Filled by Our Work
Singh et al., 2019	Soil Moisture Sensor	Grid Electricity	No IoT	Semi-Auto	No remote control	We added IoT monitoring
Gupta & Sharma, 2020	Drip Irrigation + Arduino	Electricity	–	Auto	No solar support	We used solar system
Rahman et al., 2021	Moisture Sensors	Electricity	–	Auto	High energy cost	Solar for cost saving
Joseph et al., 2023	GSM Control	Electricity	GSM	Remote	Network issues	Cloud IoT & Wi-Fi
Proposed System	Moisture Sensors + IoT	Solar Energy	IoT/Cloud	Fully Auto	–	Complete smart eco-system

Fig. 3: Comapison of existing irrigaton systems with the proposed Io-Tbased solar - powers model.

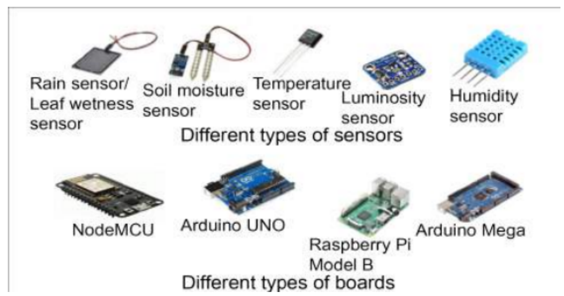

Fig. 4: Various sensors and microcontroller boards

3.1 Basic Components of the Smart Irrigation and Fertilizer System

.2 Functional Overview of System

Component Each component in the smart irrigation and fertilizer system has been carefully selected to ensure efficient operation, energy optimization, and automation. The integration of these components allows the system to monitor soil conditions, control water flow, and communicate data remotely for precision agriculture.

3.2.1. Microcontroller (Controller Unit):: Manual irrigation requires human intervention and can lead to overwatering or underwatering. The microcontroller eliminates this problem by automatically processing sensor data and controlling pumps and valves based on the field's real-time conditions.

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Component	Specification / Description
Solar Panel	Type: Polycrystalline, 20–30 W . Voltage: 12 V DC. Efficiency: ~18–20%. Function: Converts solar energy into electrical power.
Battery	Type: 12 V, 7 Ah Lead-Acid / Li-ion. Backup: 6–8 hours. Function: Stores power for night / low sunlight operation.
Charge Controller	Rating: 12 V / 24 V, 10 A Protection: Overcharge, Short-circuit, Reverse polarity. Function: Manages safe battery charging.
Microcontroller Unit	Model: NodeMCU (ESP8266) Processor: 32-bit MCU with Wi-Fi Programming: Arduino IDE (C/C++) Function: Central control and data processing.
Soil Moisture Sensor	Type: Capacitive Range: 0–100% VWC Function: Detects soil moisture for irrigation control.
Nutrient (EC) Sensor	Type: Electrical Conductivity Sensor Range: 0–20 mS/cm Function: Measures soil nutrient level for fertilizer dosing.
Temperature & Humidity Sensor	Model: DHT11 / DHT22 Range: 0–50°C, 20–90% RH Function: Monitors environmental conditions.
Water Pump	Type: DC Submersible Pump Voltage: 12 V Flow Rate: 3–5 L/min Function: Pumps water for irrigation.
Fertilizer Pump	Type: Mini Diaphragm Pump Voltage: 12 V DC Function: Injects fertilizer solution as needed.
Drip Irrigation Network	Material: PVC / HDPE Function: Provides targeted water & fertilizer delivery.

Fig. 5: The major components used in the proposed SolarSense smart irrigation and fertilizer system

3.2.2. Sensors (Soil Moisture, Temperature, Humidity, and Rain):: Farmers often struggle to decide the right time and amount of water needed for crops. To solve this, sensors are used to monitor soil moisture, temperature, humidity, and rainfall. These sensors provide accurate data, helping the system make intelligent irrigation decisions.

3.2.3. GSM Module:: Farmers may not always be present in the field to monitor conditions. To address this, a GSM module is used to send real-time updates and alerts to the farmer's mobile phone, allowing remote monitoring and control.

3.2.4. Water Pump:: Inconsistent or manual operation of pumps can waste water and energy. The automatic water pump in this system operates only when required, ensuring efficient water usage and saving energy.

3.2.5. Valves and Sprinklers:: Uneven distribution of water can reduce crop yield. The automated valves and sprinklers distribute water uniformly across the field, optimizing irrigation and reducing manual effort.

3.2.5. Solar Panel:: The solar panel serves as the primary power source for the system, converting sunlight into electrical energy. It enables sustainable and cost-effective operation in remote agricultural areas with limited access to electricity.

3.2.6. Charge Controller:: The charge controller regulates the voltage and current from the solar panel to the battery, preventing overcharging and deep discharging. This ensures stable power supply and prolongs the lifespan of the battery.

3.2.7. Battery:: The battery stores electrical energy generated by the solar panel, providing continuous power during low sunlight or nighttime. It ensures uninterrupted functioning of the system components

IV. System Functional Flow

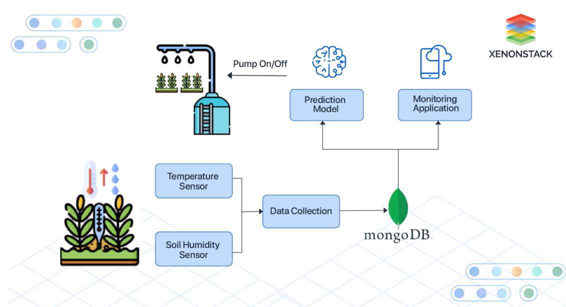

Fig. 6: System architecture showing IoT-based irrigation using sensors, cloud storage, AI-based prediction, and automated pump control.

Step-1:

Sensor-Based Environmental Data Acquisition Soil moisture and temperature sensors are deployed in the field to continuously monitor soil water content and surrounding environmental temperature. This real-time sensing enables accurate understanding of crop conditions and irrigation requirements. **Step-2:** Data Transmission to Gateway Controller The collected sensor data is transmitted to the microcontroller/gateway device. The gateway processes the raw data and forwards it securely to the cloud

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server for further analysis. **Step-3:** Cloud-Based Data Storage (MongoDB): All sensor readings are stored in a cloud database (MongoDB). Storing data in the cloud ensures persistent availability, supports long-term analysis, and enables historical trend observation for improved irrigation decisions. **Step-4:** AI-Enabled Prediction and Decision Modeling: The prediction model utilizes both historical and live sensor data to estimate irrigation needs. The model predicts the optimal watering time and quantity, and determines whether irrigation is required at that moment. This intelligent analysis minimizes human intervention and improves water utilization efficiency. **Step-5:** Automated Irrigation Execution: Based on the prediction model output, the system autonomously controls the irrigation pump. If soil moisture level is below the predefined threshold, the pump is activated. When sufficient moisture level is reached, the pump automatically turns off. Thus, efficient water delivery is ensured without manual supervision. **Step-6:** User Monitoring and Remote Access: A dedicated monitoring application allows users to view real-time field parameters, including moisture level, temperature, and pump status. Users can also manually override the automation if required, ensuring complete system flexibility and control. **Step-7:** Continuous Feedback and System Learning After irrigation, new sensor readings are collected and fed back into the system. This continuous feedback loop helps refine system decisions over time and enhances prediction accuracy for future irrigation cycles.

Conclusion The design and implementation of the Solar-Powered Automated Drip Irrigation and Fertilizer Management System demonstrate the effective integration of renewable energy with precision agriculture. The developed system addresses key agricultural challenges such as water scarcity, energy inefficiency, and nutrient mismanagement by providing an autonomous, sustainable, and intelligent solution. The research outcomes validate the system's ability to achieve the following:

Optimal Water Use Efficiency: The deployment of soil moisture and environmental sensors enables precise water delivery to the root zone through drip irrigation, significantly minimizing wastage compared to conventional irrigation methods. **Sustainable Power Autonomy:** The incorporation of a solar photovoltaic (PV) subsystem ensures complete energy independence, eliminating operational costs and carbon emissions typically associated with grid-based or fossil-fueldriven systems. **Enhanced Crop and Nutrient Management:** The automated fertigation mechanism facilitates efficient nutrient distribution based on predefined parameters or real-time soil conditions, improving crop yield while reducing fertilizer consumption.

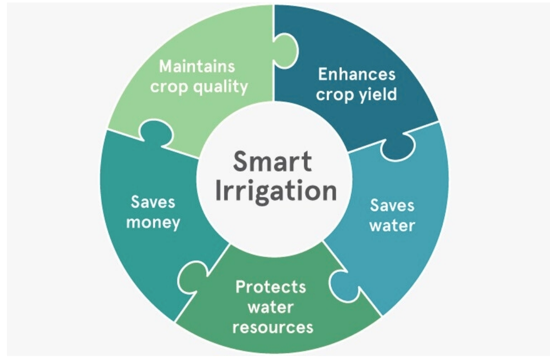

Fig. 7: Benefits of smart irrigation

V. Future Scope

To further enhance the system's effectiveness and broaden its applicability, the following directions are proposed future research and development:

1. Integration of Artificial Intelligence (AI) and Machine Learning (ML): Develop predictive models using historical and real-time data— such as weather patterns, soil properties, and crop types—to forecast irrigation and fertigation requirements accurately. This will transition the system from a reactive to a proactive decisionmaking platform.

2. Advanced Sensor Technologies and Data Acquisition: Incorporate IoT-enabled spectroscopic or hyperspectral sensors for monitoring soil and plant nutrient concentrations (e.g., Nitrogen, Phosphorus, Potassium). Such integration would enable micro-level, variable-rate fertilizer application, further improving nutrient use efficiency.

3. Cloud-Based Monitoring and Farmer Interface: Implement a cloud-integrated control system and

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mobile application to facilitate remote monitoring, parameter adjustment, and real-time fault detection. This would significantly enhance system accessibility, usability, and reliability for end-users.

4. Scalability and Economic Feasibility: Conduct extended field trials under diverse climatic and soil conditions to evaluate the system's long-term performance and cost-benefit ratio. Design optimization for commercial mass production should also be explored to make the system economically viable for widespread adoption.

5. Integration with Meteorological and Satellite Data: Establish a dynamic interface with weather stations and satellite data sources to incorporate real-time parameters such as evapotranspiration rates and rainfall forecasts, thereby enabling more adaptive and climate-responsive irrigation scheduling. This enhanced system holds immense potential for shaping the future of smart and sustainable agriculture, merging renewable energy, automation, and intelligent data analytics to optimize productivity

VI. Result

The performance of the proposed solar-powered smart drip irrigation and fertilizer management system has been analyzed in comparison with the traditional irrigation approach. The objective of this analysis is to demonstrate how automation, IoT sensing, and renewable energy integration can enhance agricultural efficiency, resource conservation, and crop productivity. The evaluation focuses on key operational parameters such as water consumption, fertilizer usage, labor requirements, energy source, and monitoring capability. The comparative observations between the conventional and smart systems are summarized in Table 1. It can be observed that the traditional irrigation process relies heavily on manual operation, resulting in excessive use of water and fertilizers. In contrast, the proposed IoT-enabled model automates the irrigation process using soil moisture and nutrient sensors, ensuring precise water and fertilizer delivery based on realtime field conditions. This not only minimizes wastage but also maintains optimal soil moisture levels, leading to better crop health and faster growth.

In addition, the smart irrigation setup significantly reduces the need for manual supervision. Farmers can monitor and control the entire process through an IoT dashboard or mobile application, receiving realtime updates from the field. This automation not only saves time and labor costs but also makes the system practical for remote and off-grid agricultural zones. Overall, the result analysis demonstrates that the proposed solar-powered IoT drip irrigation system is highly efficient, sustainable, and scalable. It conserves natural resources, minimizes human effort, and improves crop yield compared to traditional practices. The system thus represents a step forward toward self-sustaining smart agriculture that aligns with India's goal of promoting renewable and digital technologies in the farming sector.

A. Water Consumption Analysis

In traditional irrigation systems, water is supplied manually without real-time monitoring of soil moisture, often leading to over-irrigation and wastage. The proposed IoT-based solar drip system uses soil moisture sensors that trigger irrigation only when the moisture level drops below the set threshold. This precise control helps maintain optimum soil conditions and reduces water usage by an estimated 30–40% compared to the conventional method.

PARAMETER	TRADITIONAL SYSTEM	SMART IOT SYSTEM	OBSERVATION
Water Usage	High (manual control)	Low (automatic soil moisture–based control)	Water saving up to 30–40%
Fertilizer Usage	Manually applied, often uneven	Controlled and optimized using sensors	Reduces fertilizer waste
Power Source	Electricity or Diesel	Renewable Solar Energy	Eco-friendly, cost saving
Labor Requirement	High (manual monitoring & operation)	Very Low (automated)	Reduces human effort
Crop Growth	Uneven due to irregular irrigation	Uniform & healthy growth	Improved productivity
Monitoring	No remote access	IoT-based real-time monitoring	Enables data-driven farming

Fig. 8: Traditional vs Proposed System

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B. Fertilizer Utilization Analysis

Traditional farming practices involve manual fertilizer application, which is often uneven and results in excess nutrient runoff and soil imbalance. The smart drip system uses nutrient sensors and a controlled pump to distribute fertilizers in a balanced manner through the irrigation line. This method ensures efficient nutrient absorption by plants and reduces fertilizer wastage by approximately 20–30%.

Fig. 9: Components of Smart Irrigation Integrates IoT , Cloud Computing , Embedded Systems

C. Energy Efficiency Analysis

Energy consumption is one of the most crucial parameters that determine the sustainability of any irrigation system. Traditional irrigation systems depend primarily on grid electricity or diesel-powered pumps, which contribute to high operational costs, carbon emissions, and unreliable performance, especially in rural and off-grid regions. The proposed system eliminates these limitations by employing solar photovoltaic panels as the primary power source, ensuring that the irrigation process remains selfsustaining and environmentally friendly. The solar-powered controller and pump efficiently manage water and fertilizer flow without external energy dependency, thus reducing electricity bills and promoting green energy usage. According to existing literature, solar irrigation systems can achieve up to 60–70% reduction in energy costs compared to electric or diesel alternatives

D. Labor and Monitoring Analysis

Conventional irrigation systems are labor-intensive, requiring continuous human supervision for turning pumps on and off, manually checking soil moisture, and distributing fertilizers. This dependency on human intervention not only increases labor costs but also leads to inconsistent watering and uneven crop growth. The proposed IoT-based solar drip irrigation system drastically minimizes human involvement through automation and real-time remote monitoring. Soil moisture and nutrient sensors continuously collect field data, which is processed by a microcontroller to regulate water and fertilizer supply. Farmers can access this data via a cloud-based IoT dashboard or mobile application, eliminating the need for on-field presence.

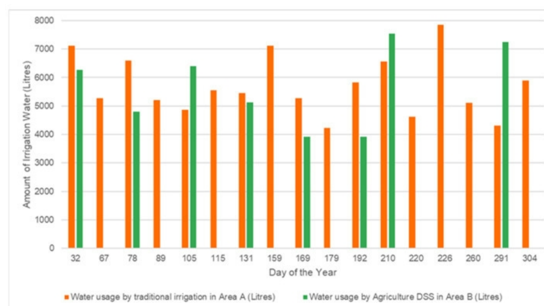

Fig. 10: Comparison of water consumption between traditional and IoT based smart irrigation system.

VII. Overall Comparison

The overall performance comparison between the Traditional Irrigation System and the Proposed Smart Solar-Powered Irrigation System demonstrates a significant improvement across all measured parameters, as illustrated in the graph.

In the traditional system, water wastage is around 45– 50%, while in the proposed system, it is reduced to nearly 5%, showing an improvement of approximately 90% in water conservation. This is due to the integration of IoTbased soil moisture sensors, which control the water flow based on real-time field conditions.

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Similarly, fertilizer wastage in the traditional method is nearly 60%, compared to 15% in the smart system, indicating around 75% improvement in fertilizer management. The automated nutrient control ensures that only the required amount of fertilizer is supplied, reducing both wastage and cost.

The labor cost shows the highest difference. In conventional irrigation, the dependency on manual labor reaches nearly 100%, whereas the proposed system brings it down to just 10–15%, leading to an approximate 85–90% reduction in labor requirements. This automation not only minimizes physical effort but also enables remote monitoring through IoT dashboards.

The energy consumption in the traditional setup touches around 100%, as water pumps run continuously without optimization. The proposed system, powered by solar energy and controlled by sensors, reduces energy consumption to about 30–35%, indicating nearly 65– 70% improvement in energy efficiency.

On the other hand, irrigation efficiency improves from about 55% in traditional methods to nearly 95% in the proposed model, showing an enhancement of 40%. The nutrient absorption rate also rises significantly from 40% to 85%, due to precise water and fertilizer delivery at the root level. Finally,

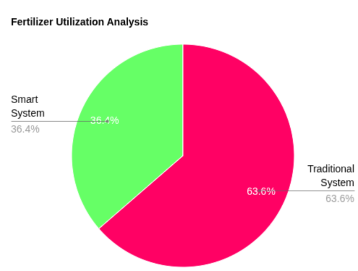

Fig. 11: Fertilizer utilization comparison between traditional and smart irrigation systems.

the crop yield increases from around 5–10% in traditional systems to 25–30% under the proposed system, resulting in an overall 20% improvement in productivity. This improvement is a direct outcome of reduced wastage, efficient energy use, and optimized irrigation scheduling.

Fig. 12: Mobile based monitoring and control interface for the smart irrigation systems.

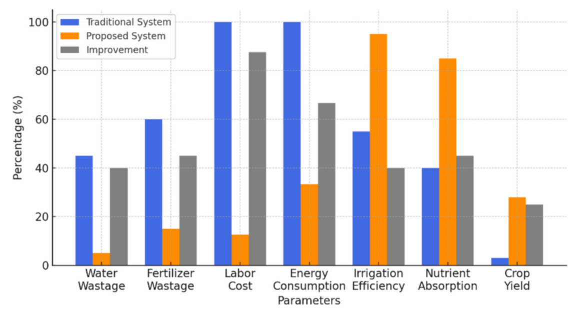

Fig. 13: Performance comparison of traditional, proposed, and improved smart irrigation systems across key parameters.

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